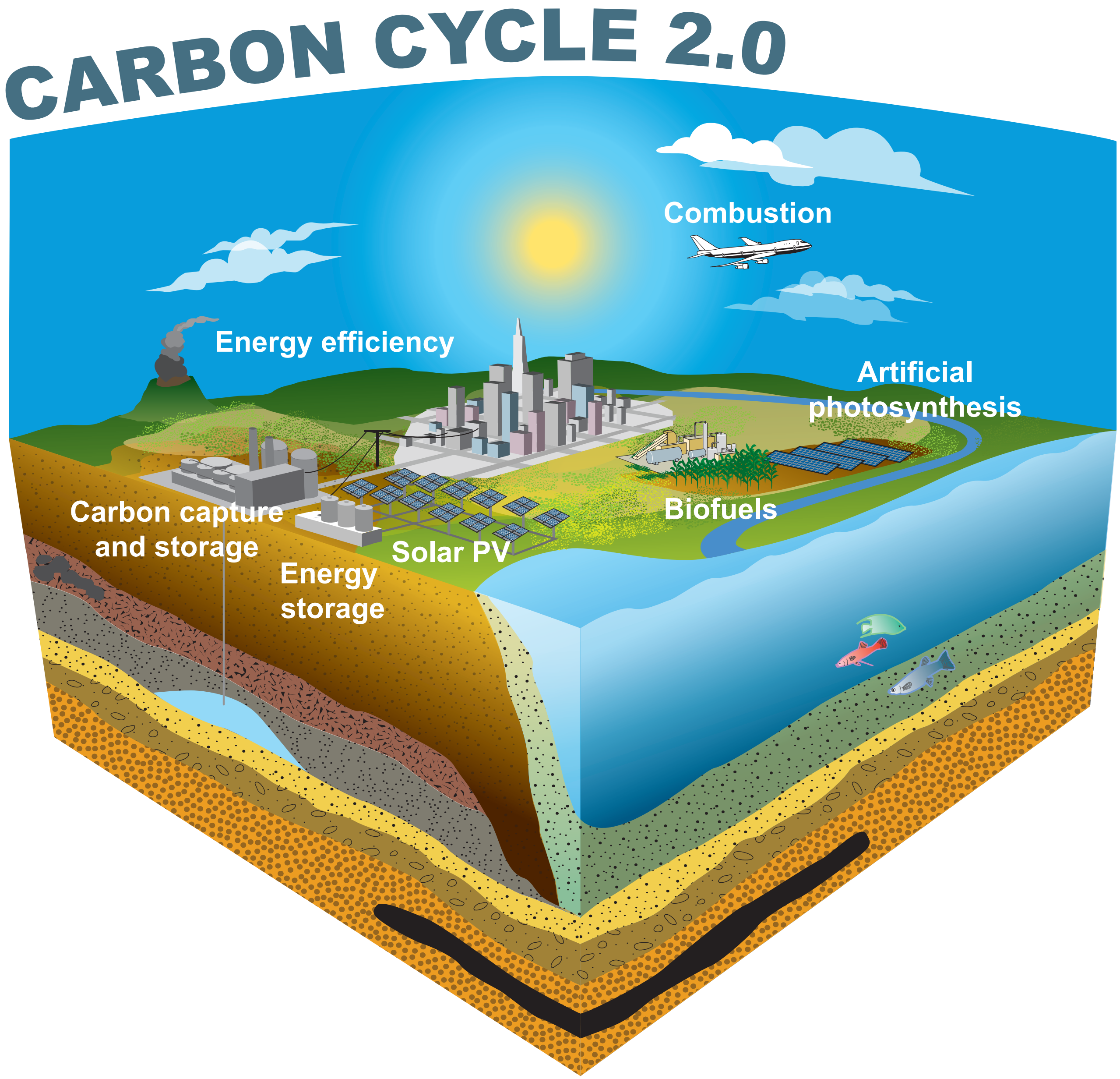
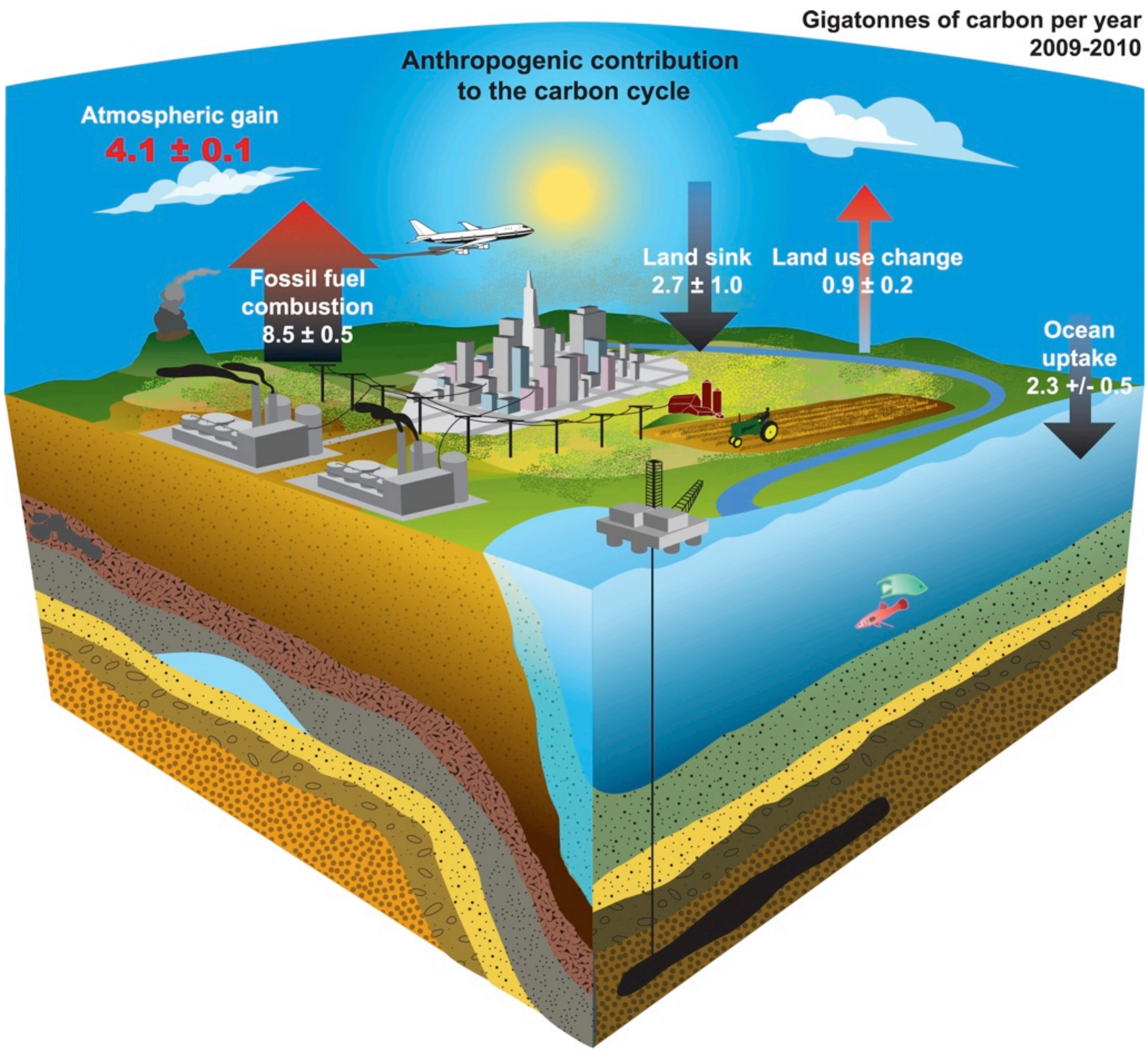
A positive vision for restoring balance to the carbon cycle, while allowing for global growth in population and wellbeing

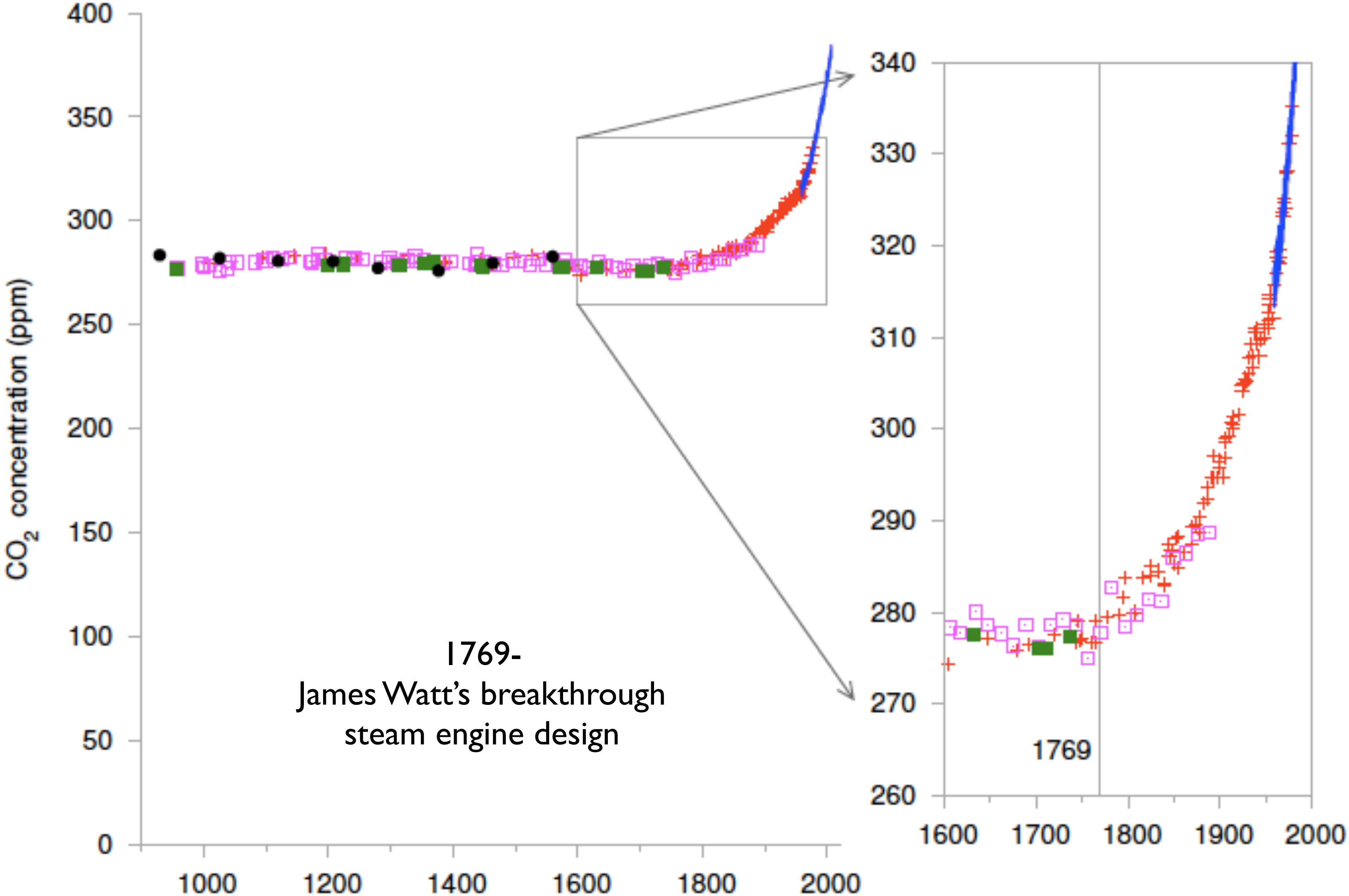


Presented by
Paul Alivisatos
Berkeley Lab,
January 31, 2011

Net flux of C due to human activity ~100X natural geological flux



Our topic for today:



from "Sustainable Energy Without the Hot Air, David Mackay

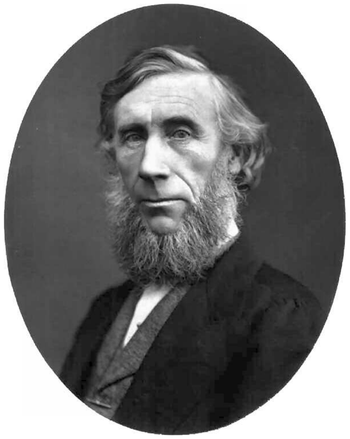
Does an increase in atmospheric CO_2
influence the Earth's temperature?

Is CO_2 increasing, and is that increase due to human activity?

Can't we simply adapt to any changes
that might arise from changes in CO_2?

Greenhouse Gas and Climate Change
Classics of the 19th Century

Jean-Baptiste Fourier,
1824 and 1827



John Tyndall
1859

Svante Arrhenius
1896

This history and more is described in “The Discovery of Global Warming,” by Spencer Weart
and on the website: http://www.aip.org/history/climate/index.htm

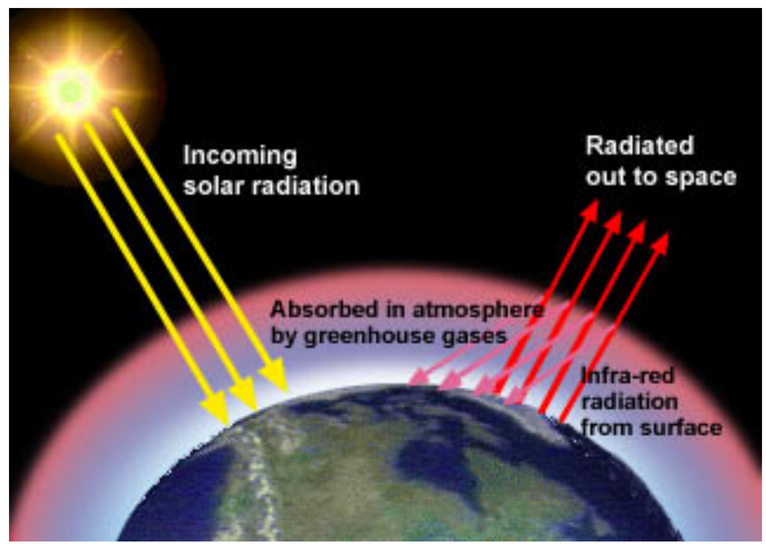
Jean-Baptiste Fourier, 1824 and 1827

Theory of heat and radiative transfer
First calculations well below freezing

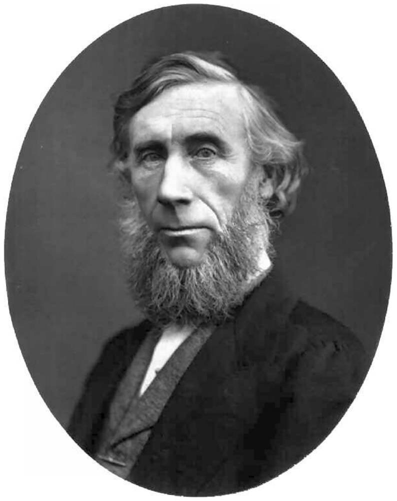
...The heat of the Sun, arriving in the form of visible light, has the ability to penetrate transparent solid or liquid substances, but loses this ability almost completely when it is converted, by its interaction with the terrestrial body, into dark radiant heat...

This distinction between luminous heat and dark heat explains the increase of temperature caused by transparent bodies.

"...the surface of the Earth is located between one solid mass, whose central heat may surpass that of incandescent matter, and an immense region whose temperature is below the freezing point of mercury..."



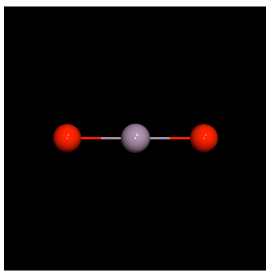
Correct calculation of the temperature of the Earth
requires taking account of the atmosphere, the **"Greenhouse effect"**

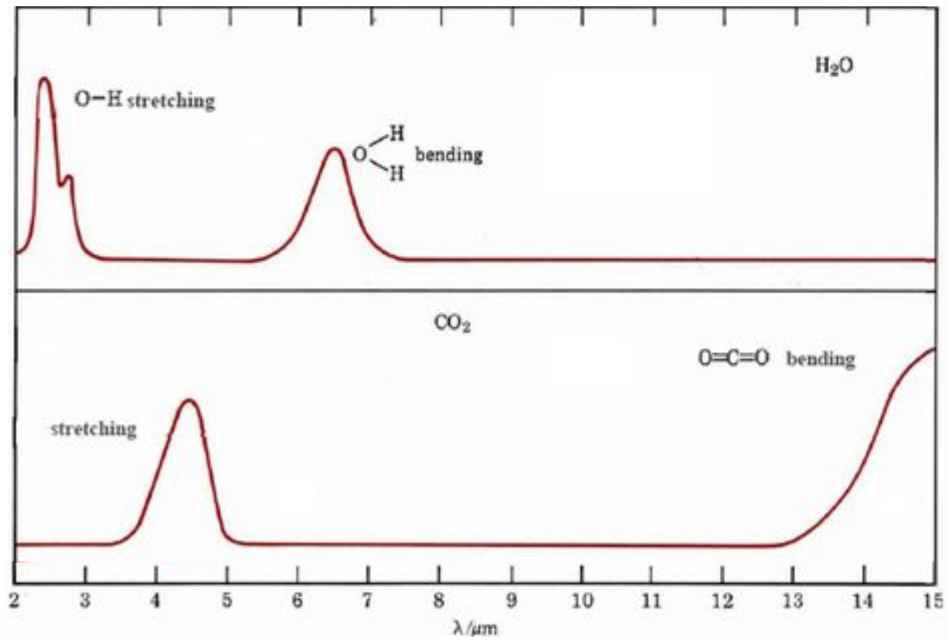


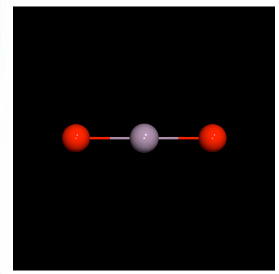
John Tyndall, 1859

IR absorption of gases

Physical basis for influence of Water and CO_2 on Earth's temperature







"As a dam built across a river causes a local deepening of the stream, so our atmosphere, thrown as a barrier across the terrestrial [infrared] rays, produces a local heightening of the temperature at the Earth's surface."

"Without water, the Earth's surface would be held fast in the iron grip of frost."

...today we know that this is true for CO_2 as well.

Svante Arrhenius' 1896 Paper

Prof. S. Arrhenius *on the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.*

Philosophical Magazine and Journal of Science
Series 5, Volume 41, April 1896, pages 237-276.

THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* *By* Prof. SVANTE ARRHENIUS *.

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.
† 'Heat a Mode of Motion,' 2nd ed. p. 405 (Lond., 1865).
‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.
§ *Comptes rendus*, t. vii. p. 41 (1838).

2x CO_2 in the atmosphere,
T goes up by 5^0 C
Later refined his calculation
to include *feedbacks* to get 2.1^0 C

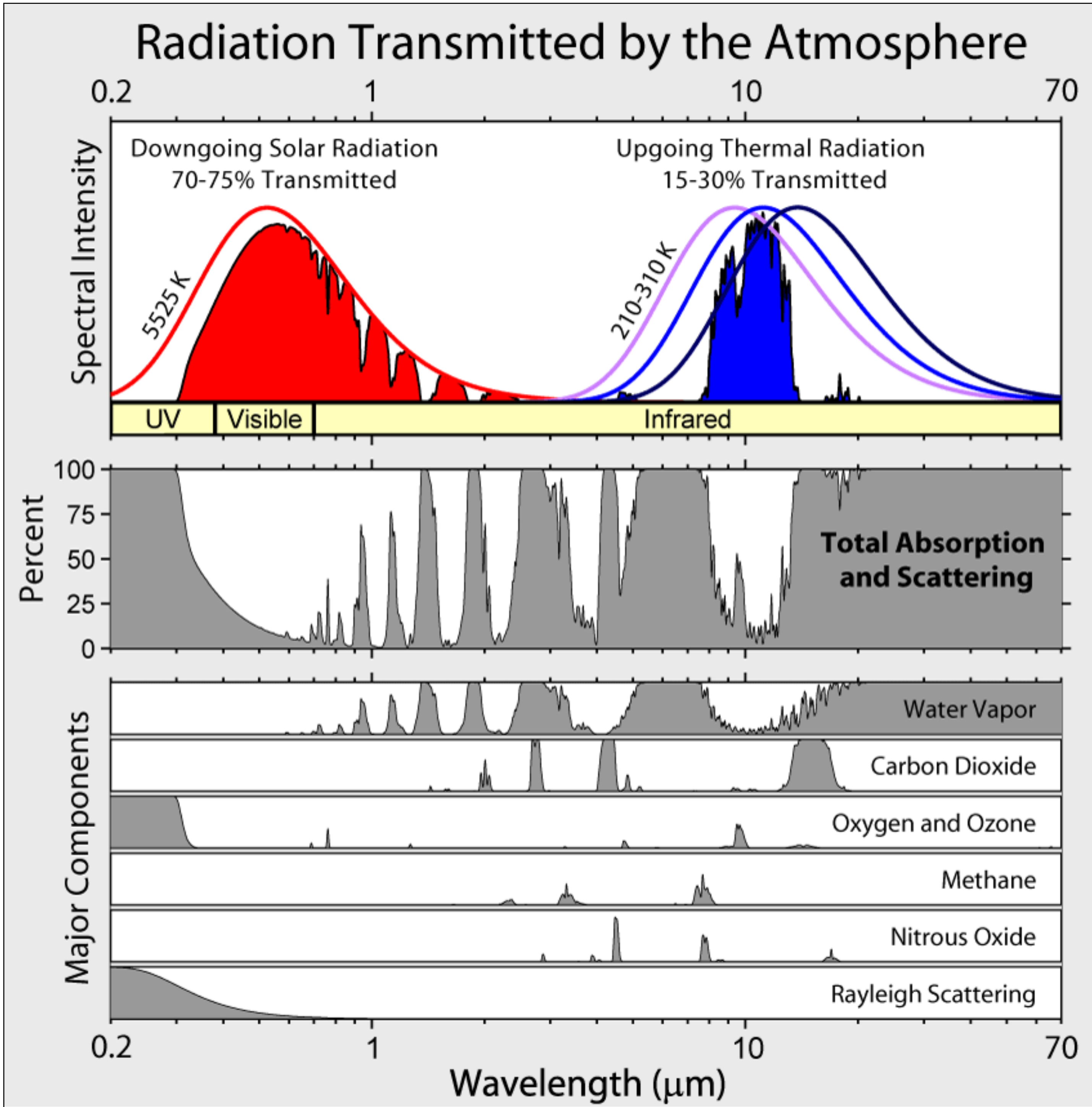
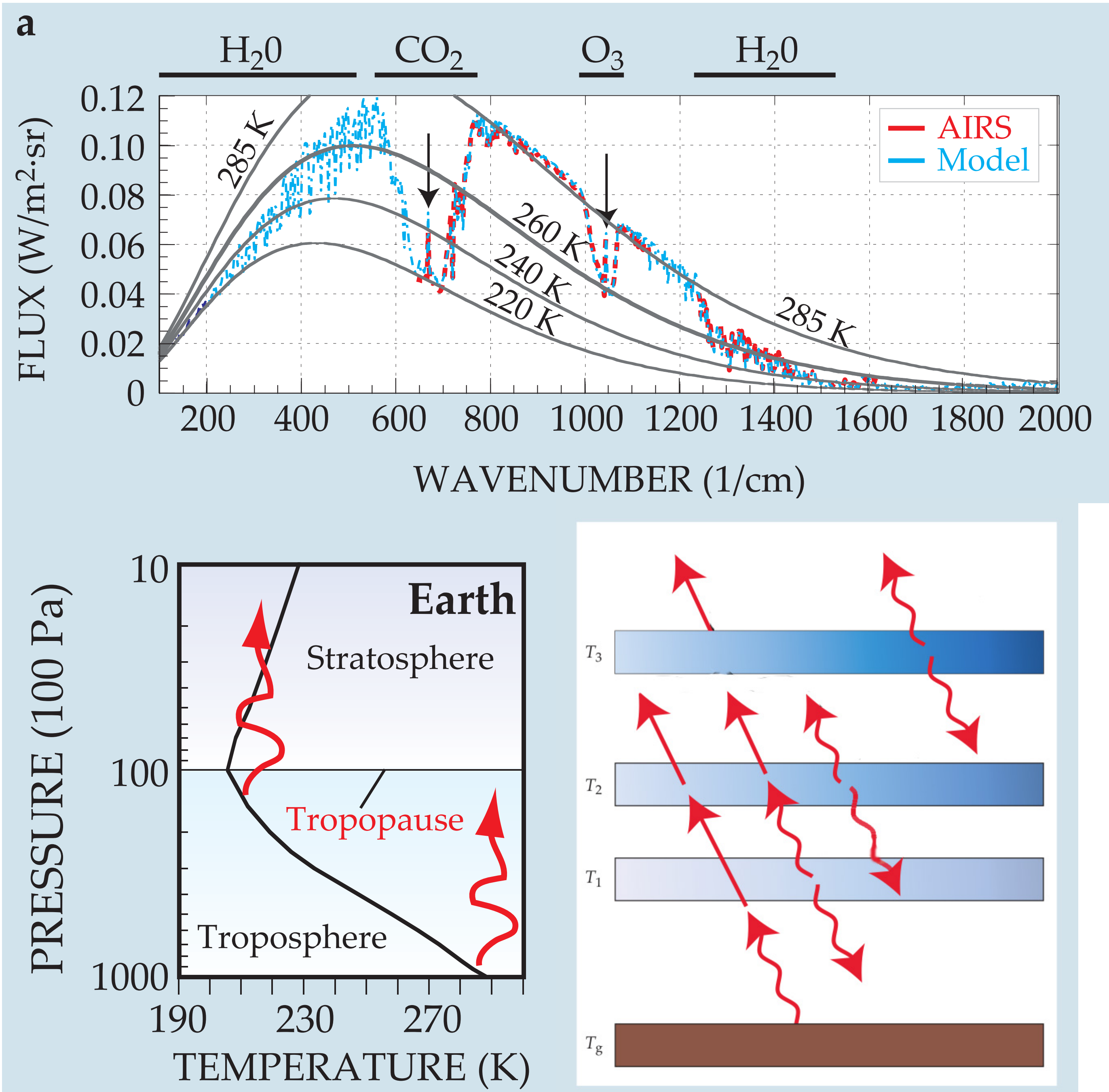


Image created by
Robert A. Rohde
Global Warming Art

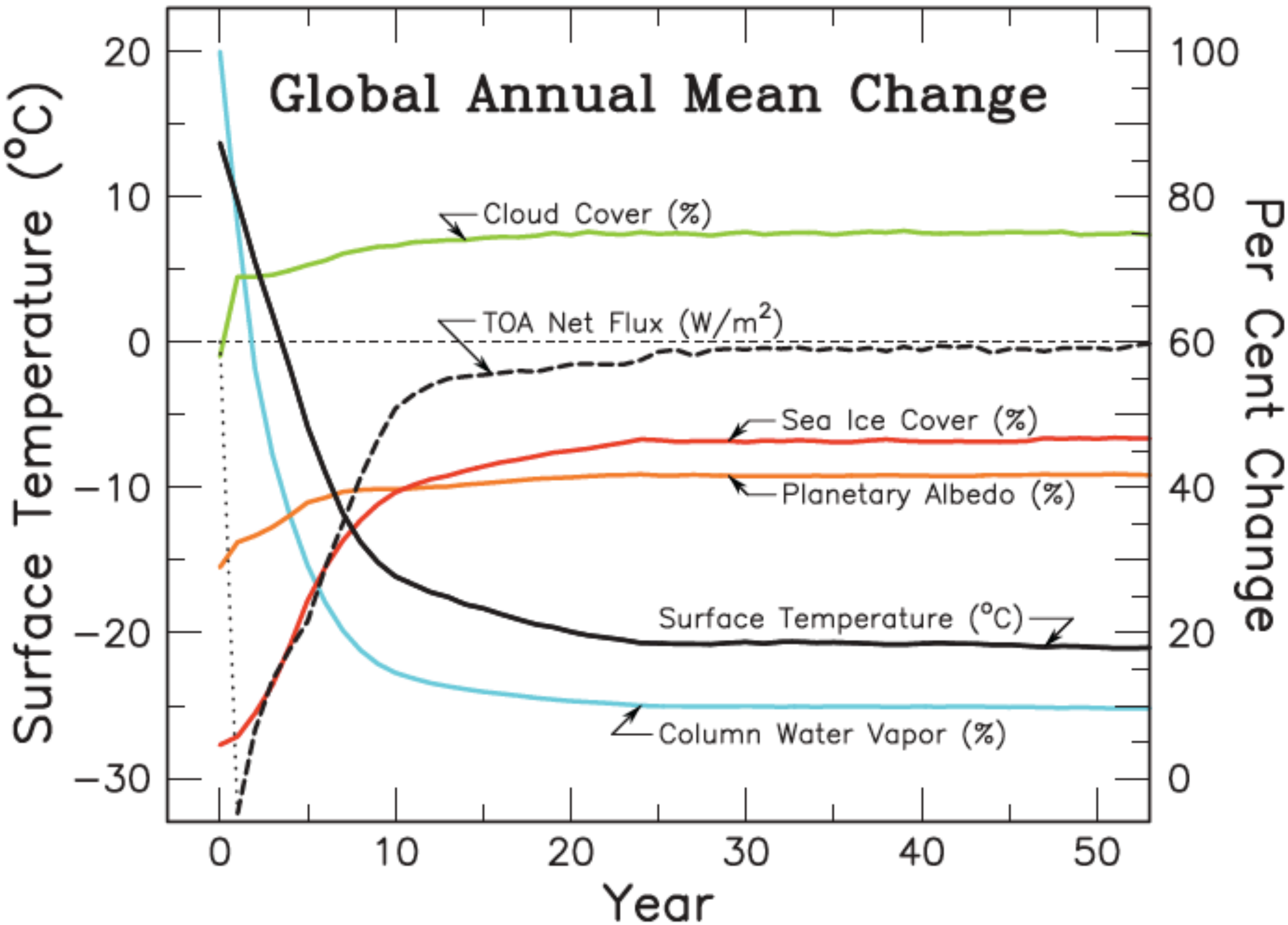
"The HITRAN 2004 molecular spectroscopic database". *Journal of Quantitative Spectroscopy & Radiative Transfer* **96**: 139-204.

One level deeper on understanding the surface warming effect of atmospheric CO_2



from R. T. Pierrehumbert, Physics Today, January 2011

CO_2 as a control knob



In the relevant temperature regime, water condenses, while carbon dioxide does not

Models show that "snowball earth" would arise if all CO_2 were abruptly removed from the atmosphere

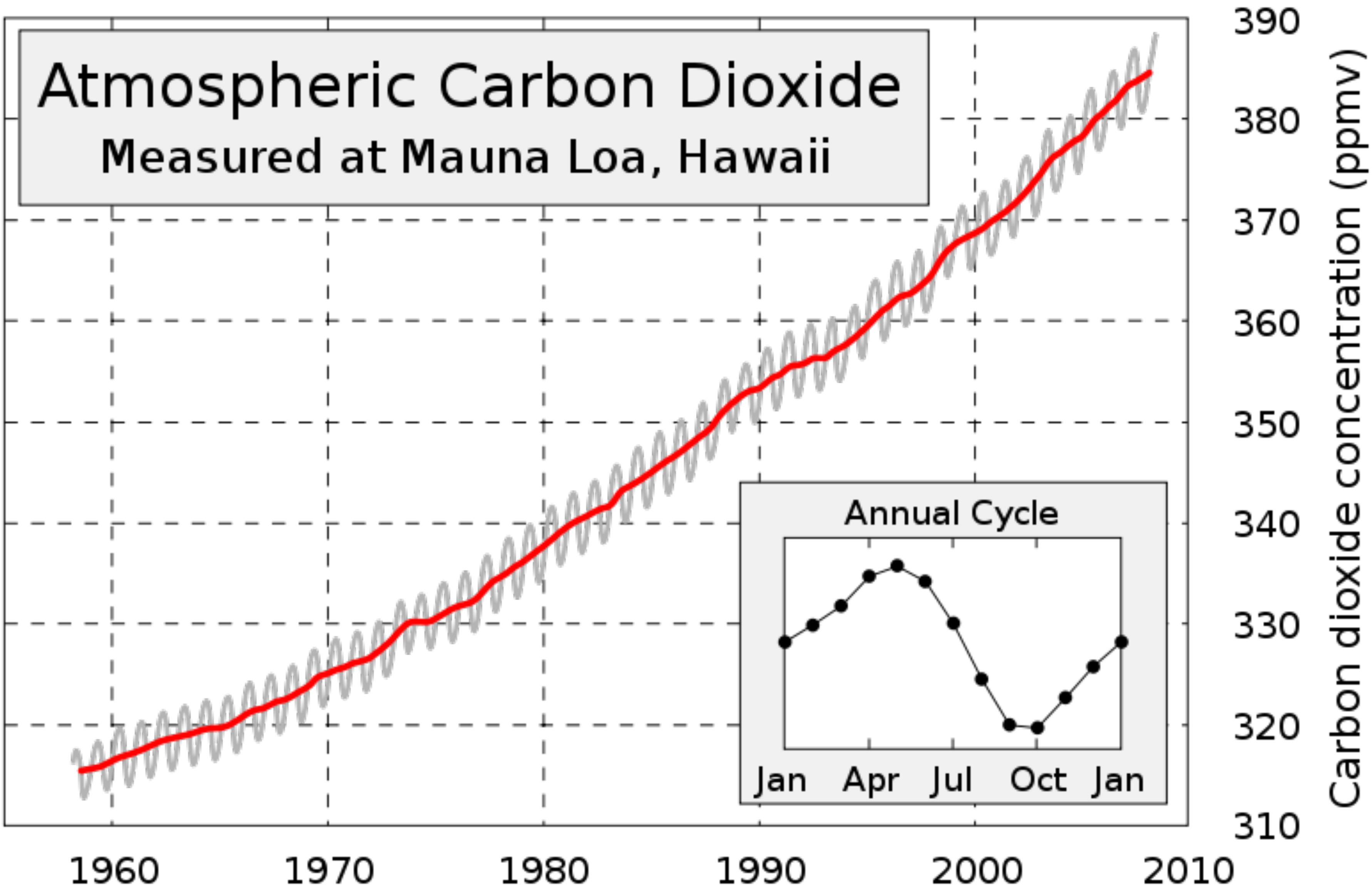
Lacis, *et al. Science* **330**, 356 (2010)

Does an increase in atmospheric CO_2
influence the Earth's temperature? **Yes**

Is CO_2 increasing, and is that increase due to human activity?

Can't we simply adapt to any changes
that might arise from changes in CO_2?

The Keeling Curve: CO_2 *is* increasing



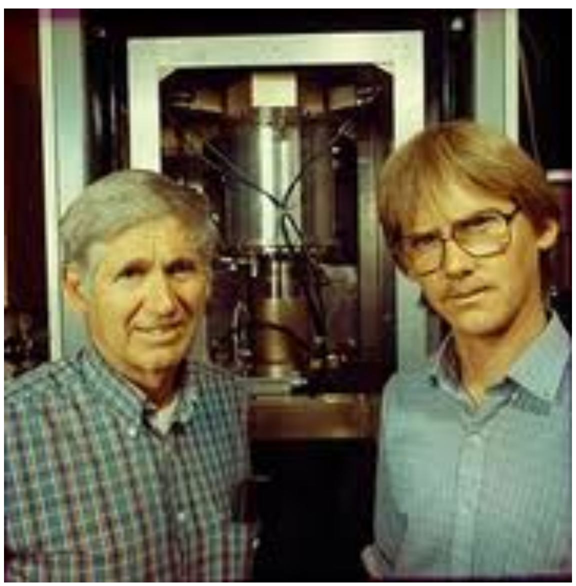
Data available at: ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_mm_mlo.txt

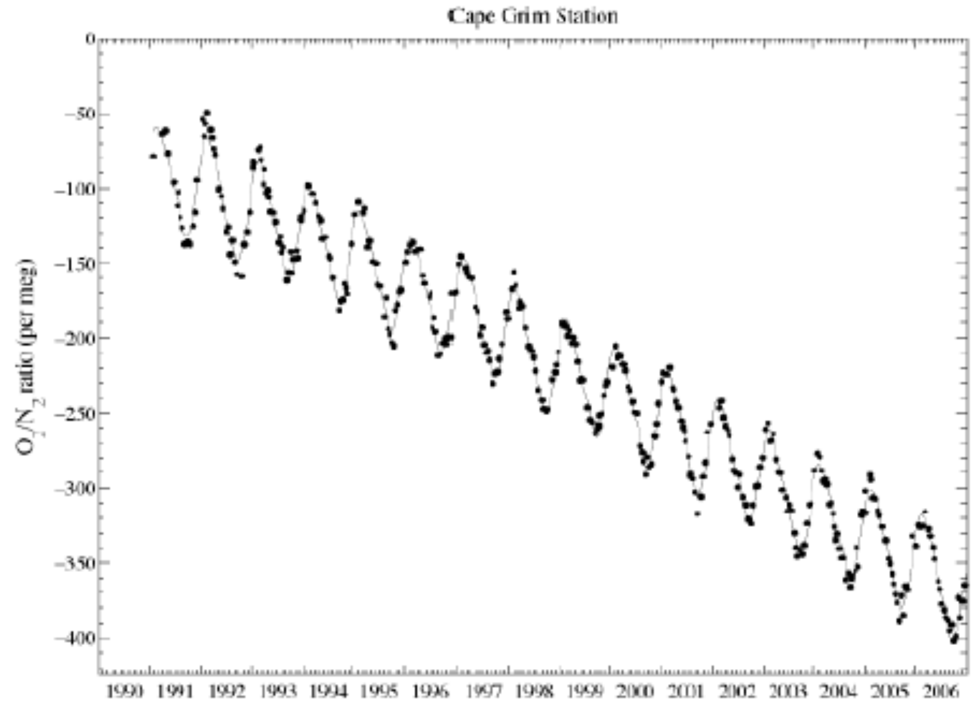
Image created by Robert A. Rohde / Global Warming Art

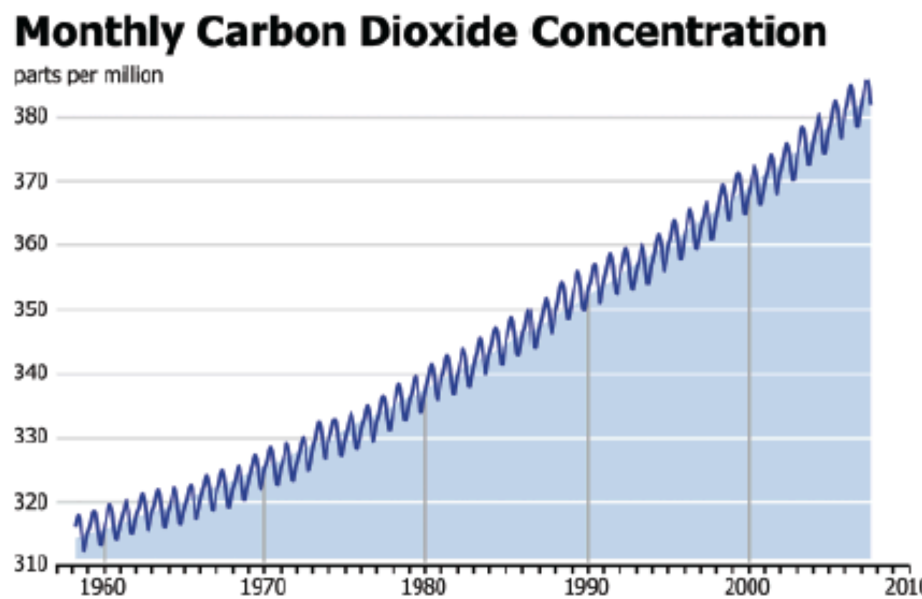
The second Keeling curve: Oxygen decrease

$$CH_n + O_2 \longrightarrow CO_2 + n/2H_2O$$

If CO_2 is increasing,
then O_2 must be decreasing,
and ***it is***



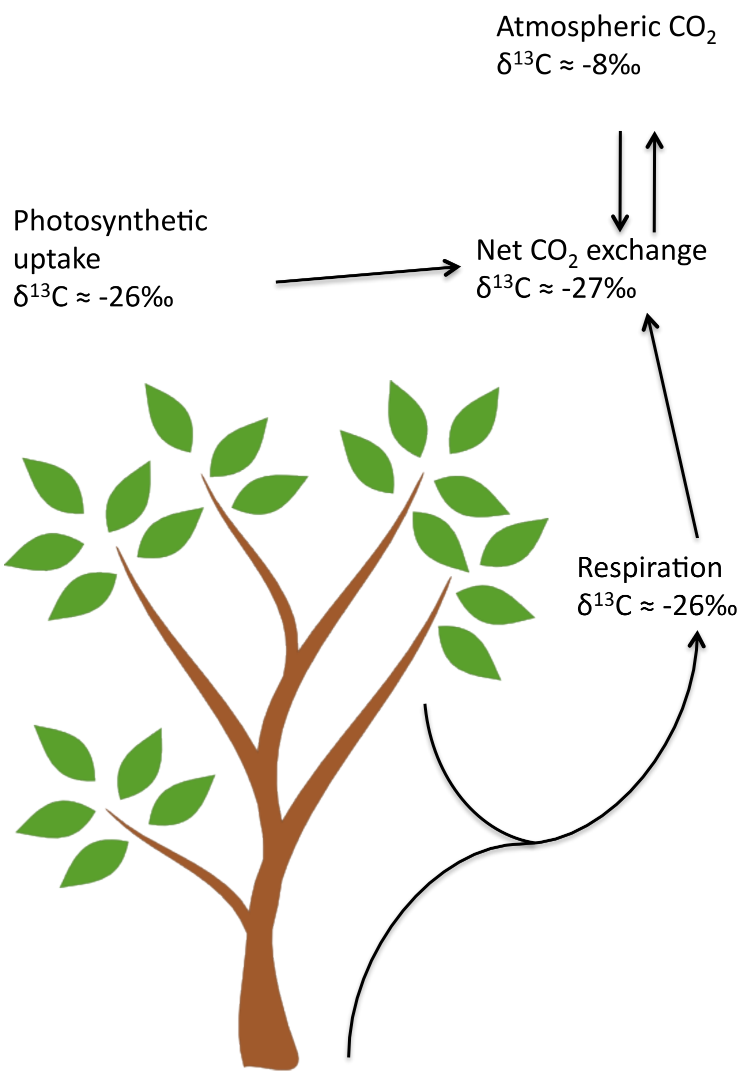


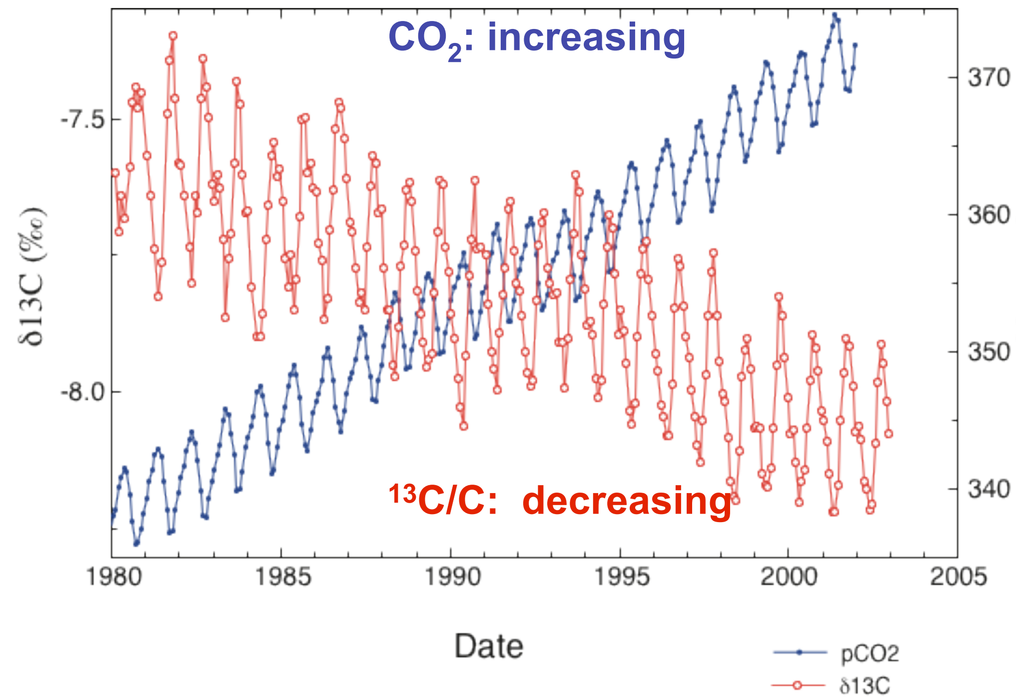


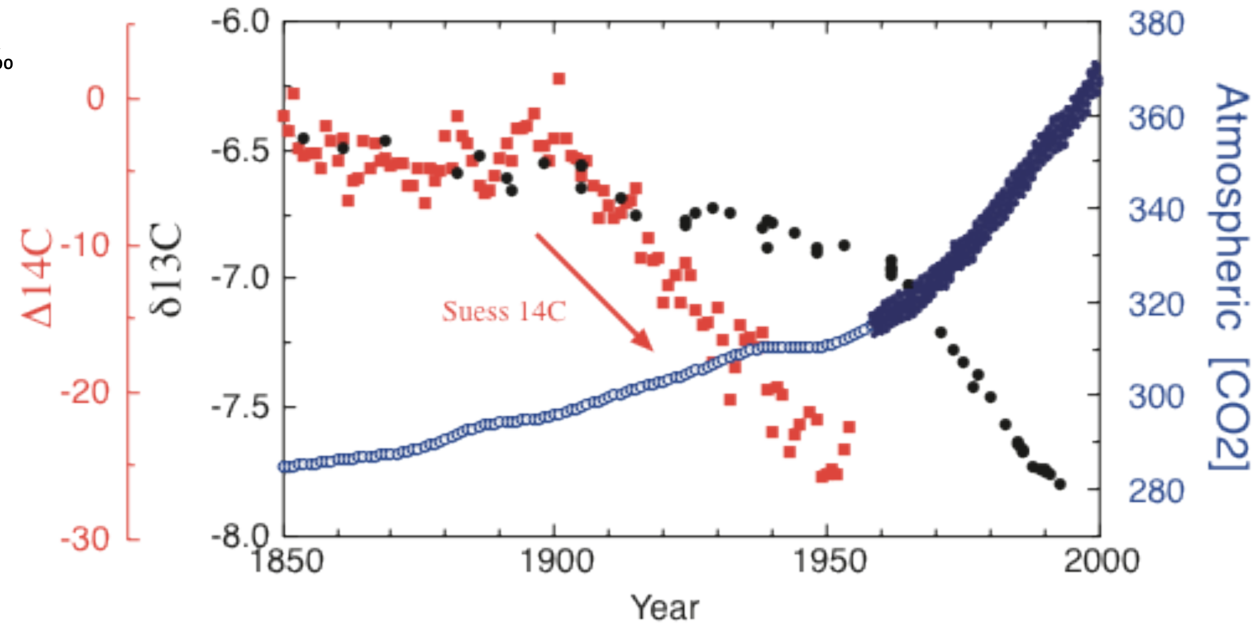
Keeling RF Nature 1996
Scripps Institute "Explorations" Magazine January 2008

Isotopic enhancement of ^{12}C: a signature of fossil fuel emissions

$$\delta^{13}C_{sample} = \left[\left(\frac{^{13}C/^{12}C_{sample}}{^{13}C/^{12}C_{standard}}\right) - 1\right] \times 1000$$

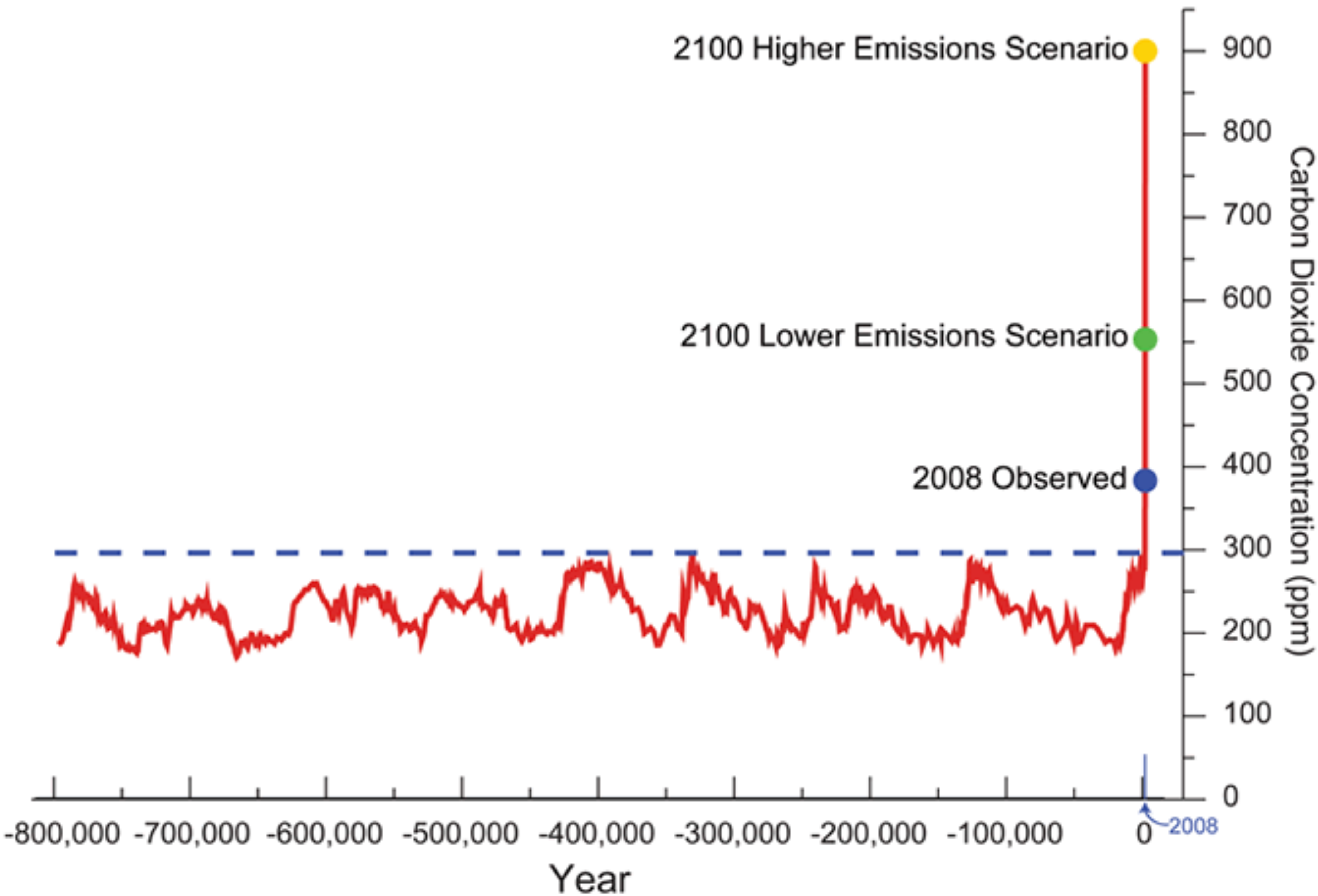




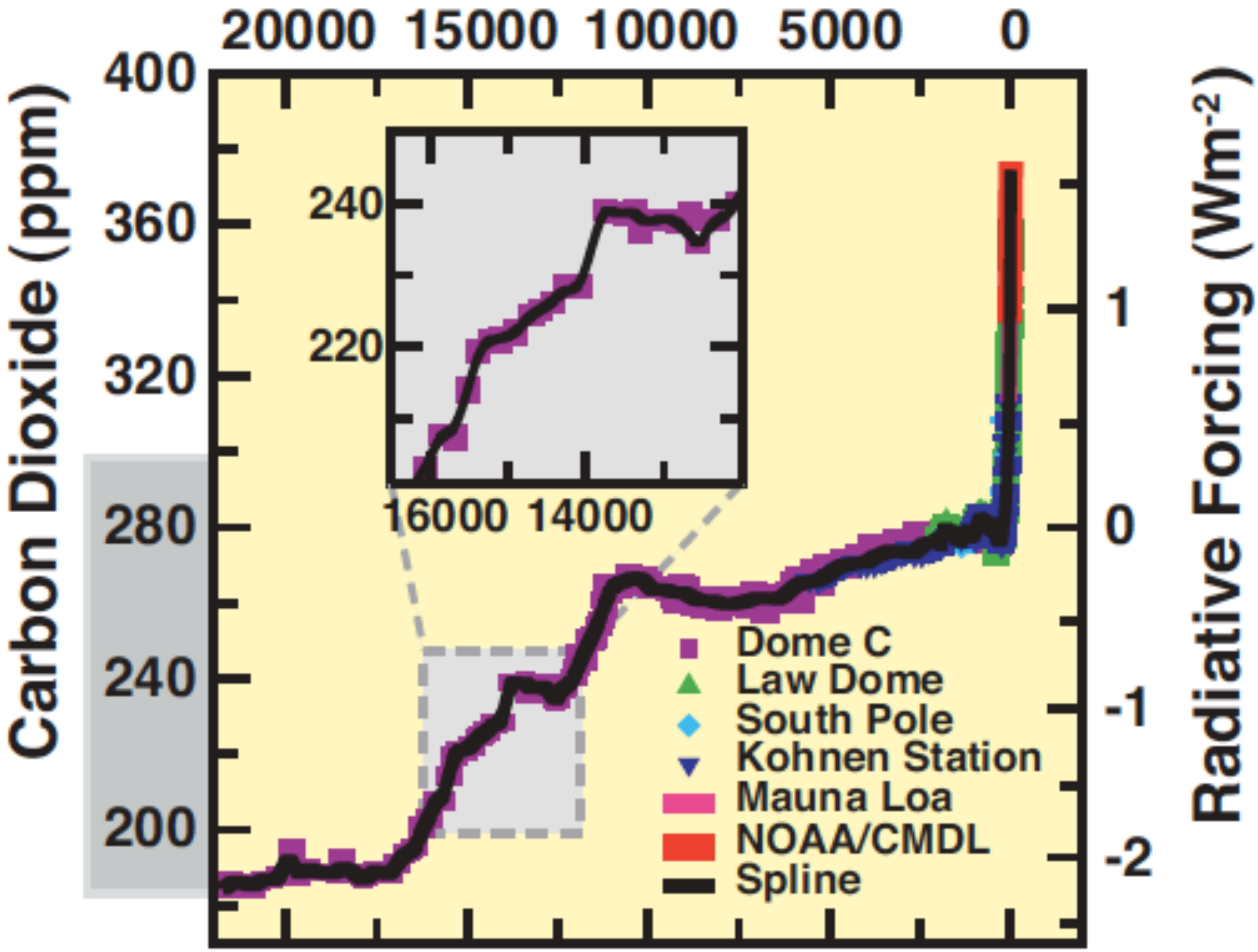


see for instance, Ghosh and Brand, International Journal of Mass Spectrometry (2003) vol. 228 pp. 1-33

Atmospheric CO_2 over 800,000 years



Abruptness of the time scale of change

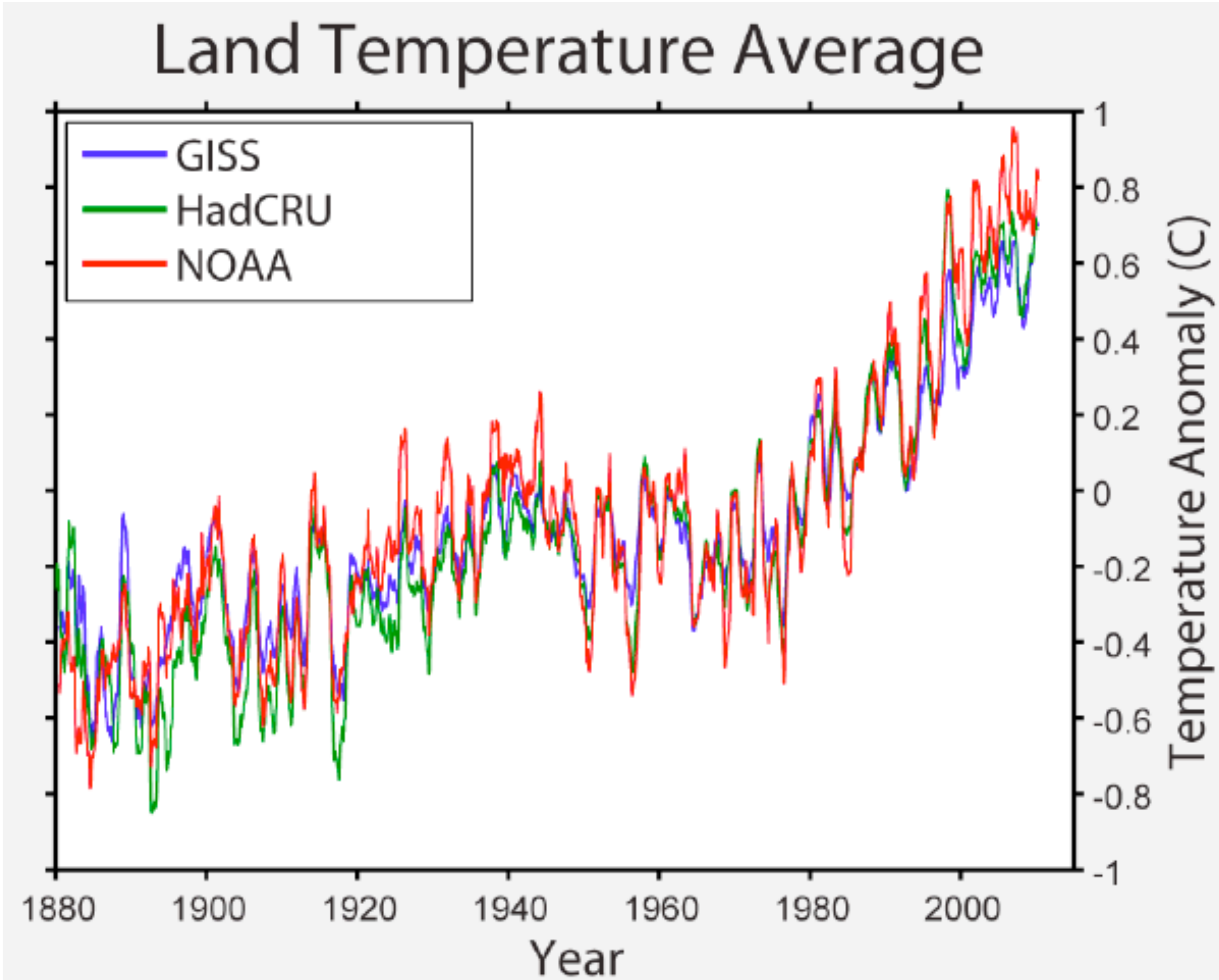


Does an increase in atmospheric CO_2
influence the Earth's temperature? **Yes**

Is CO_2 increasing, and is that increase due to human activity?
Yes

Can't we simply adapt to any changes
that might arise from changes in CO_2?

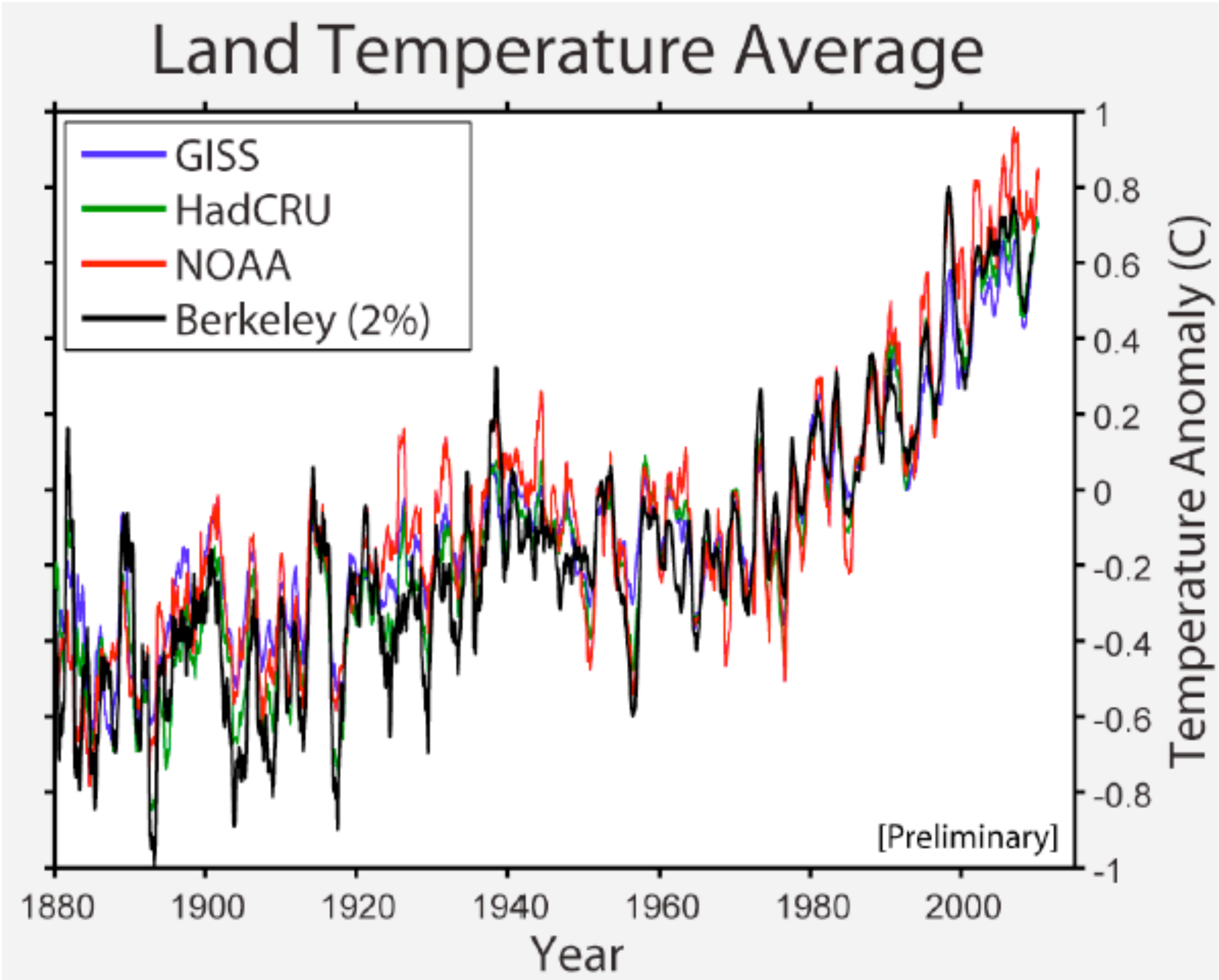
The global mean temperature record since 1880...



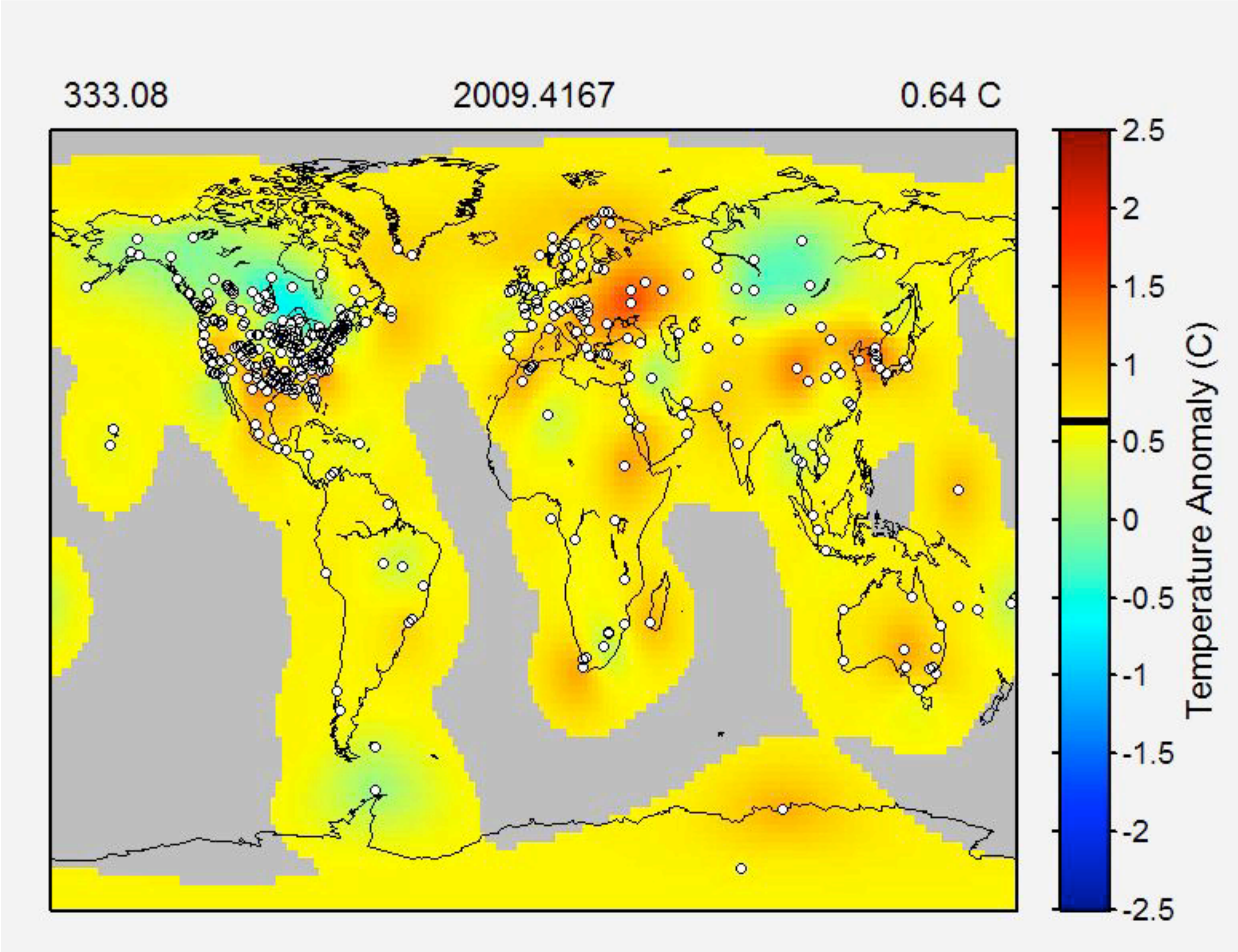
IPCC 2007

The global mean temperature record since 1880...

Berkeley Earth Surface Temperature Analysis

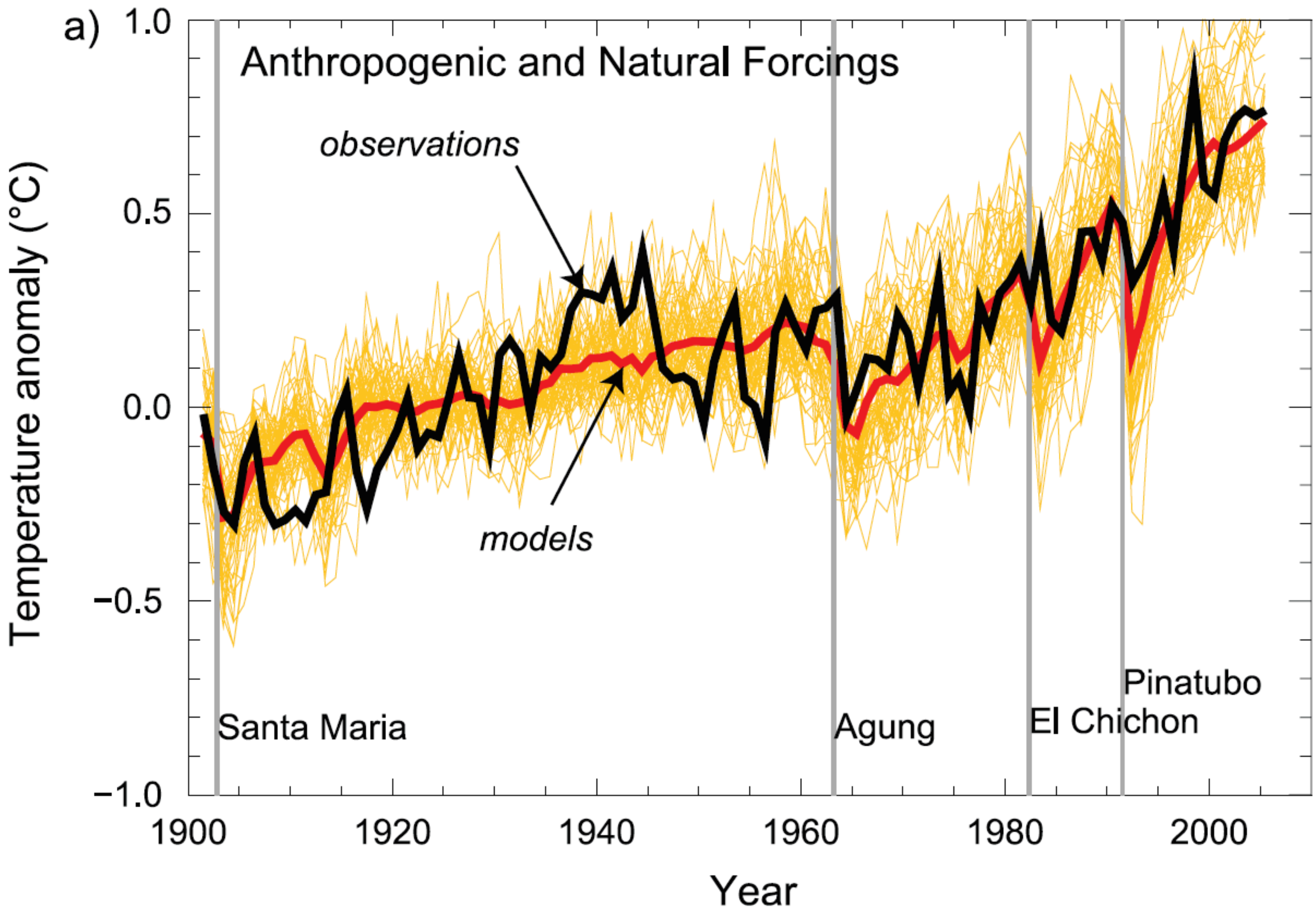


David Brillinger, Judith Curry, Robert Jacobsen, Elizabeth Muller, **Richard Muller (chair)**, Saul Perlmutter, **Robert Rohde**, Arthur Rosenfeld, Charlotte Wickham, Jonathan Wurtele

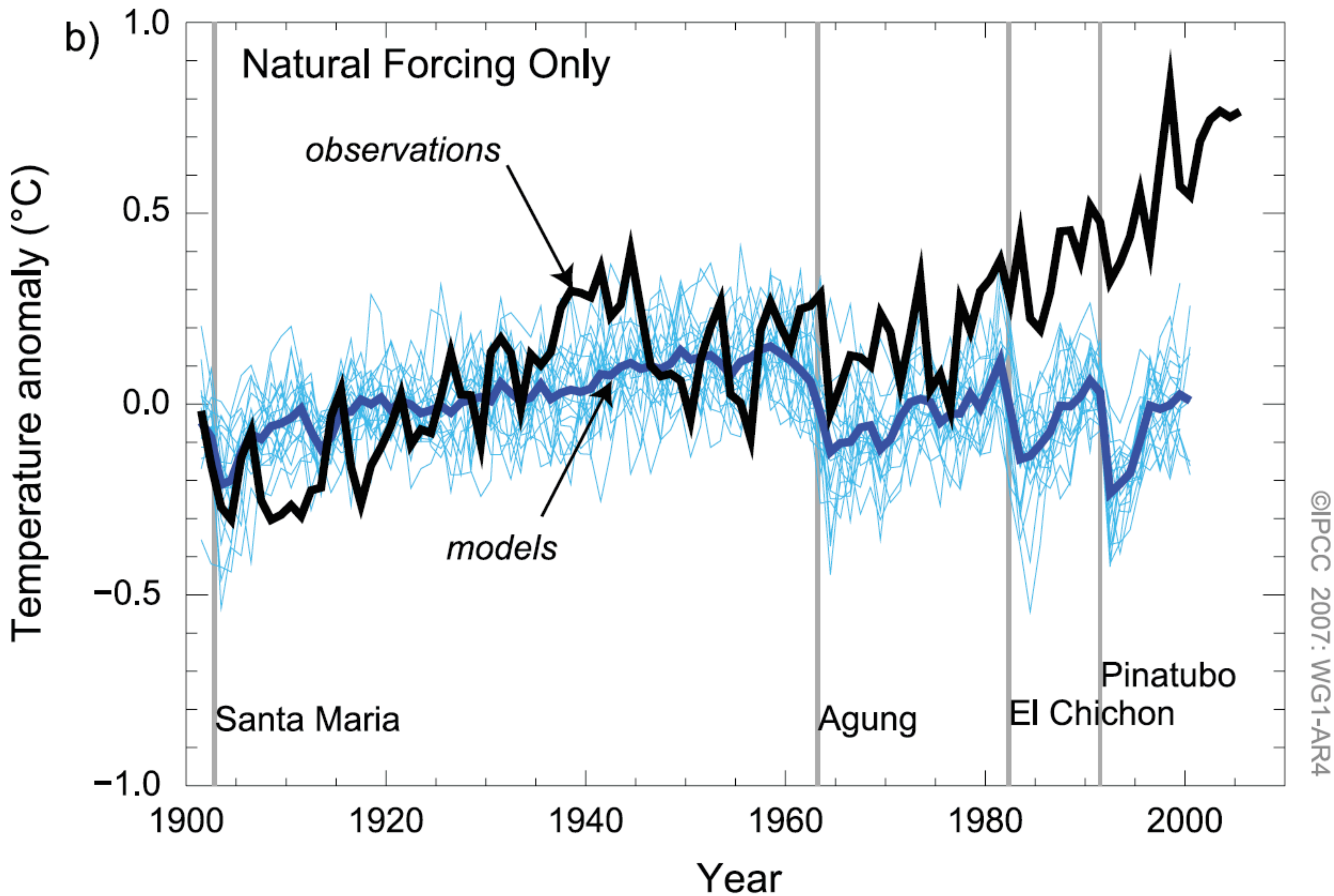


Berkeley Earth Surface Temperature Analysis

The global mean temperature record - comparison to models...



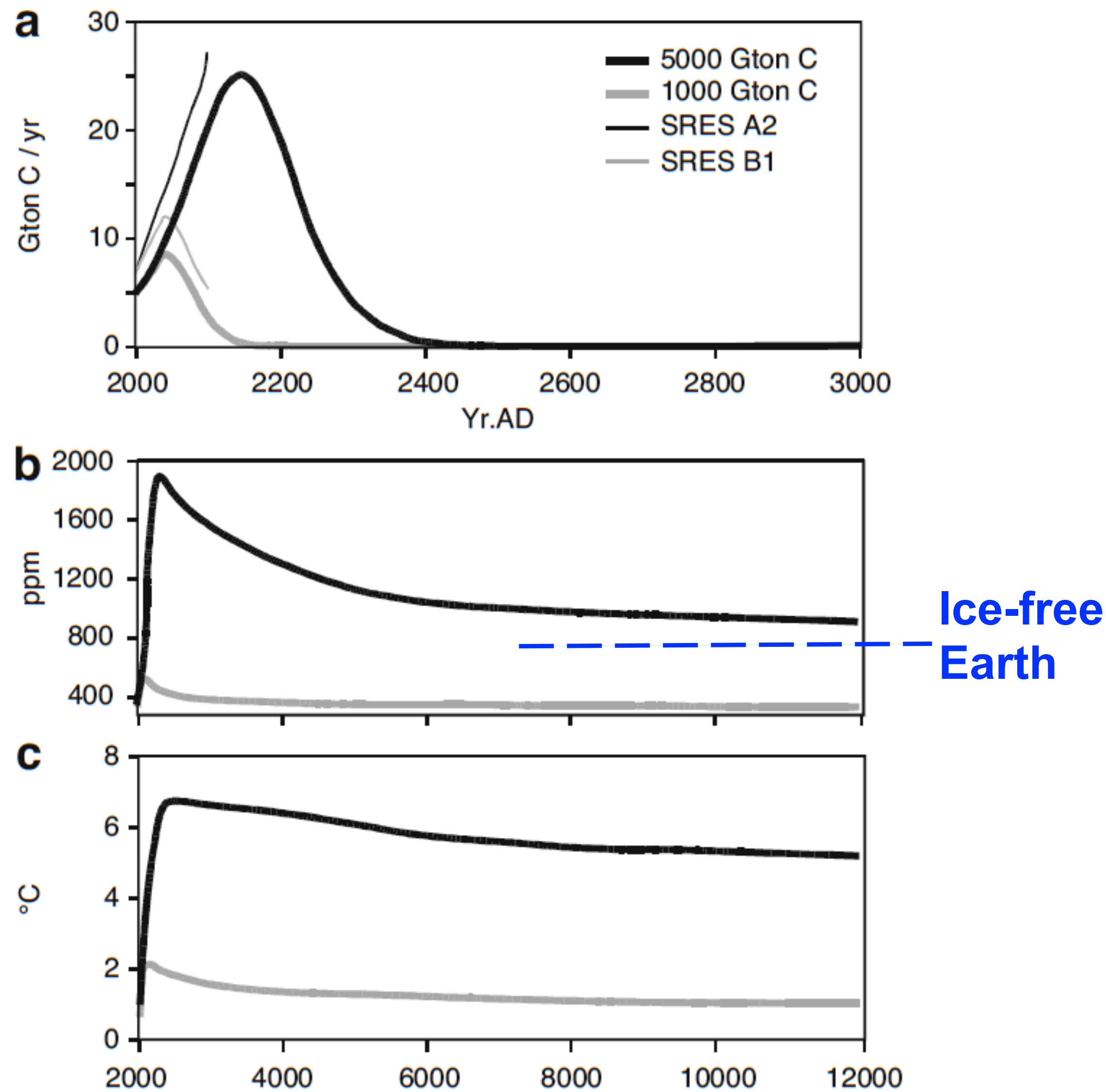
The global mean temperature record - comparison to models...

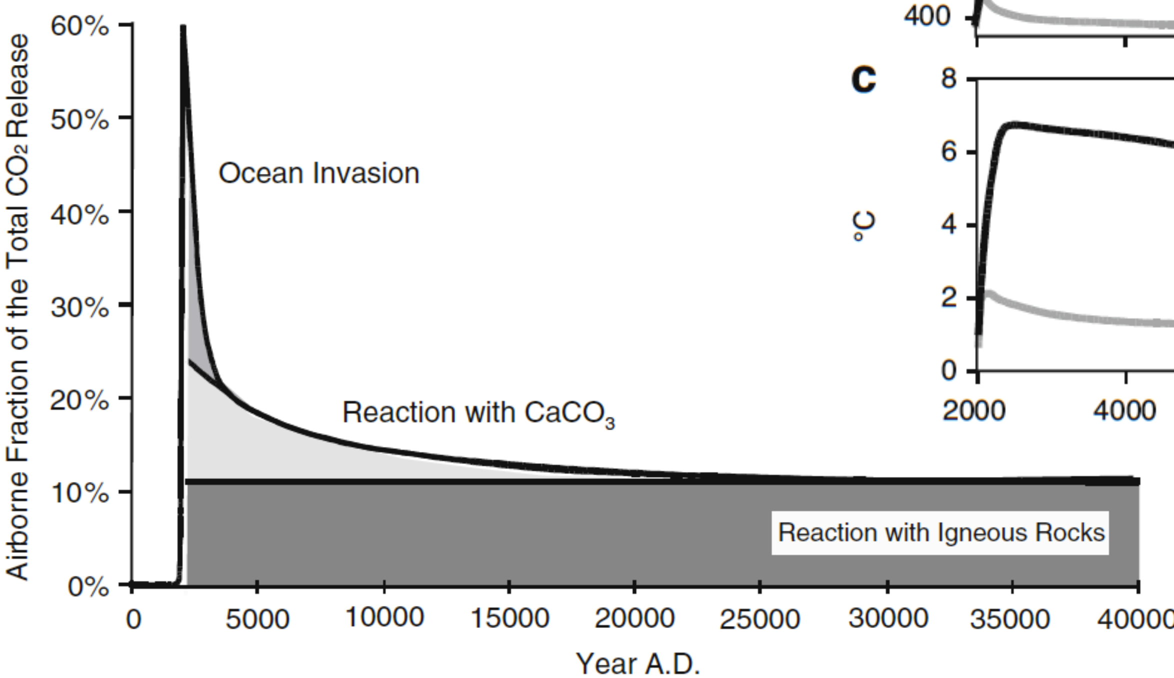


Constraint #1: The long term effects of CO_2 may persist for 10^5 yr

Best case:
1000Gt CO_2 emitted

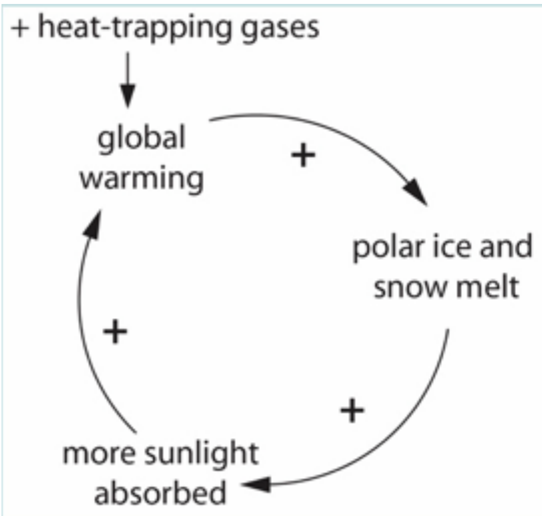
Worst case:
5000Gt CO_2 emitted

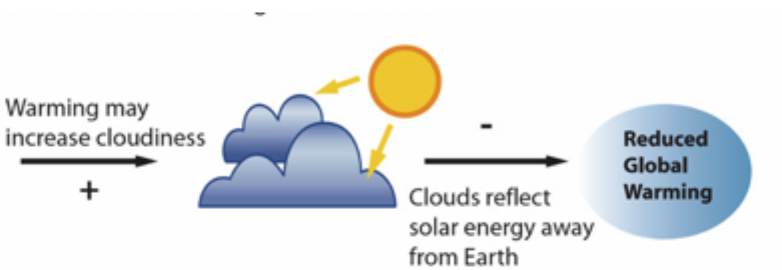


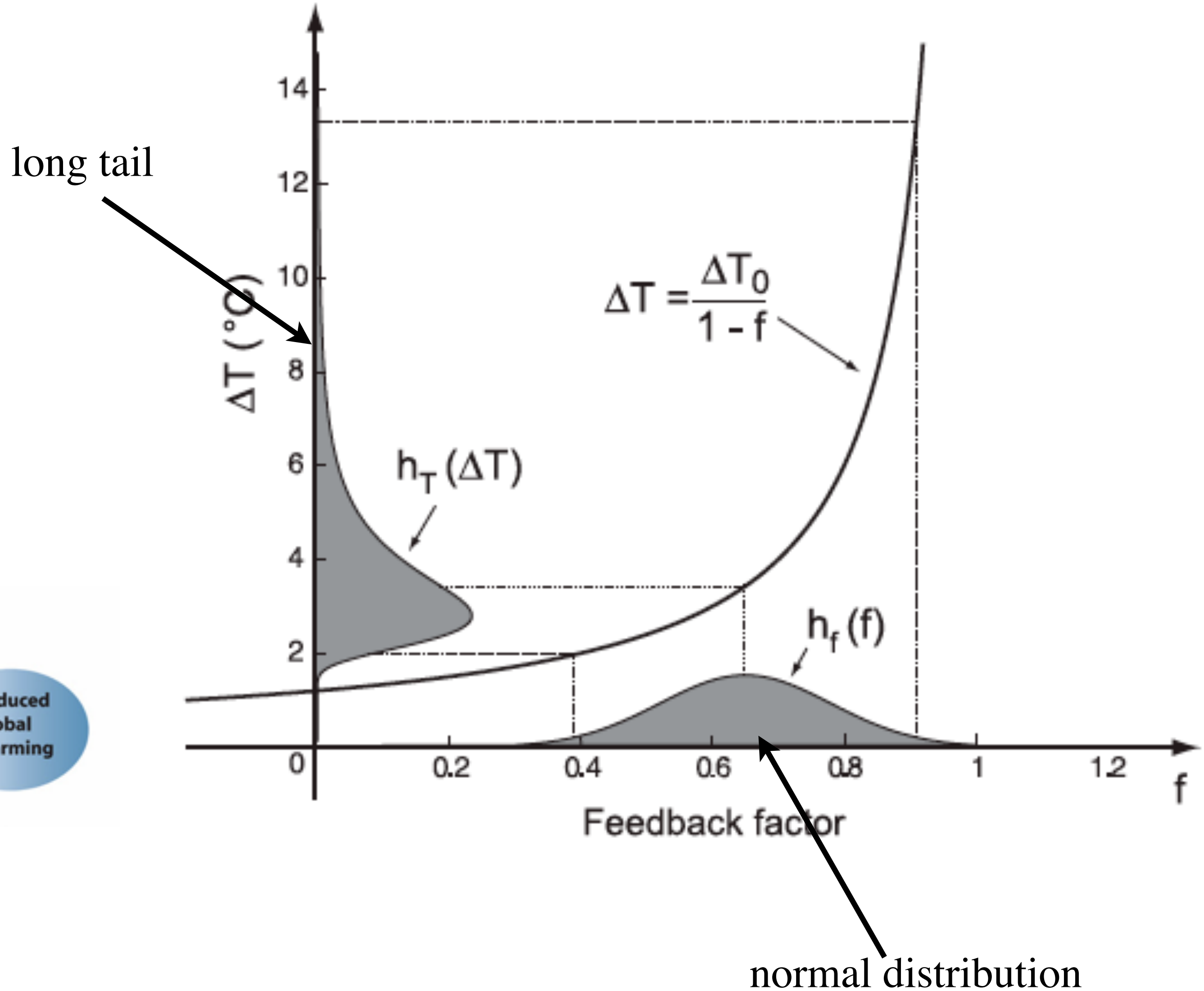


Archer & Brovkin, 2007

Constraint #2 - We do not know all the feedbacks in the system

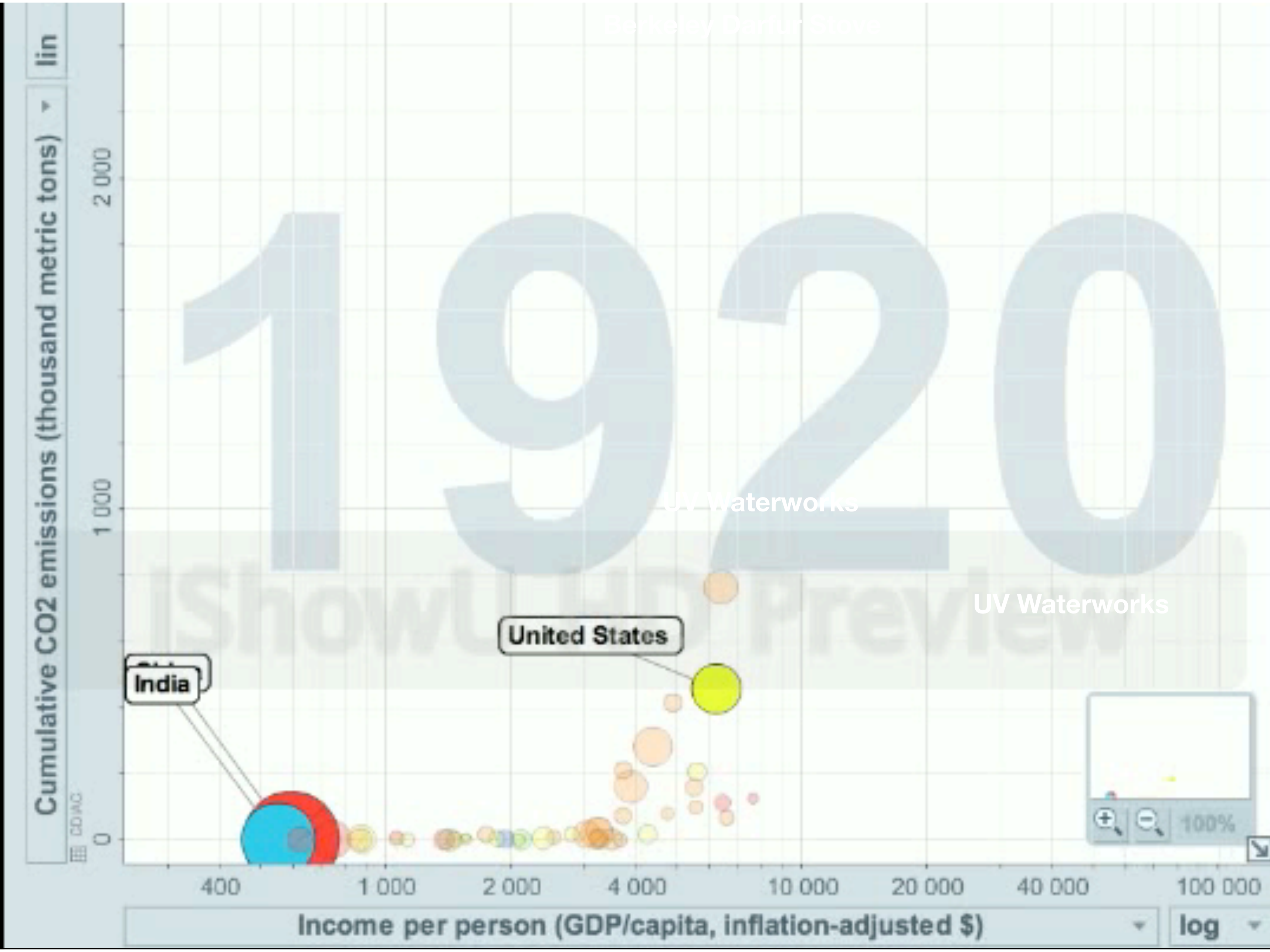




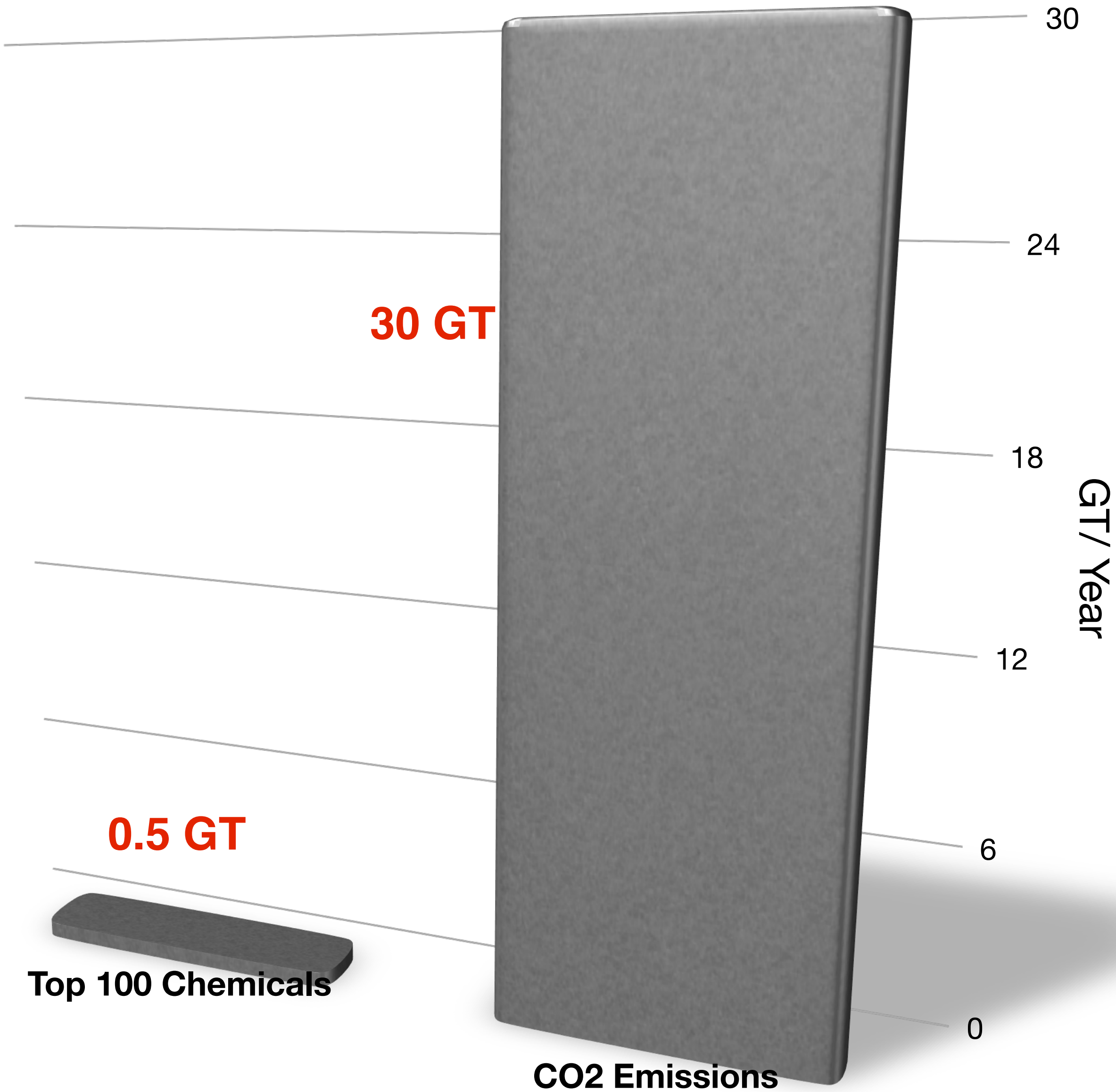


"Why is climate sensitivity so unpredictable?", Roe and Baker, Science **318**, 629 (2007)

Constraint #3 - the developing world will and should develop



Constraint #4: - *scale* of the problem a challenge and an opportunity



8.2 M bpd

2.5 M bpd

CNPC PetroChina

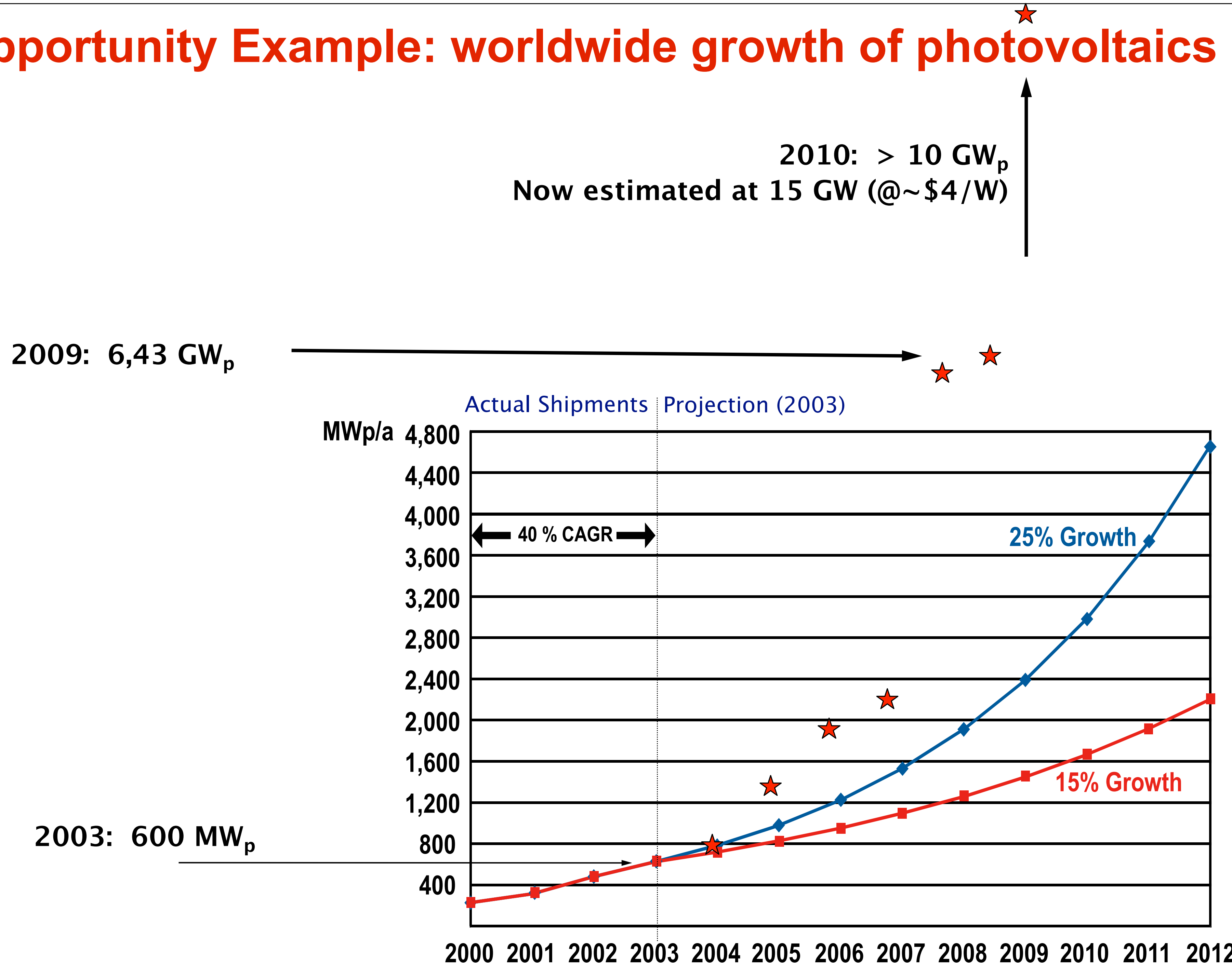
Abu Dhabi

Kuwait

Venezuela

bpd = barrels per day

Opportunity Example: worldwide growth of photovoltaics



Courtesy Eicke Weber, Fraunhofer Institute for Solar Energy

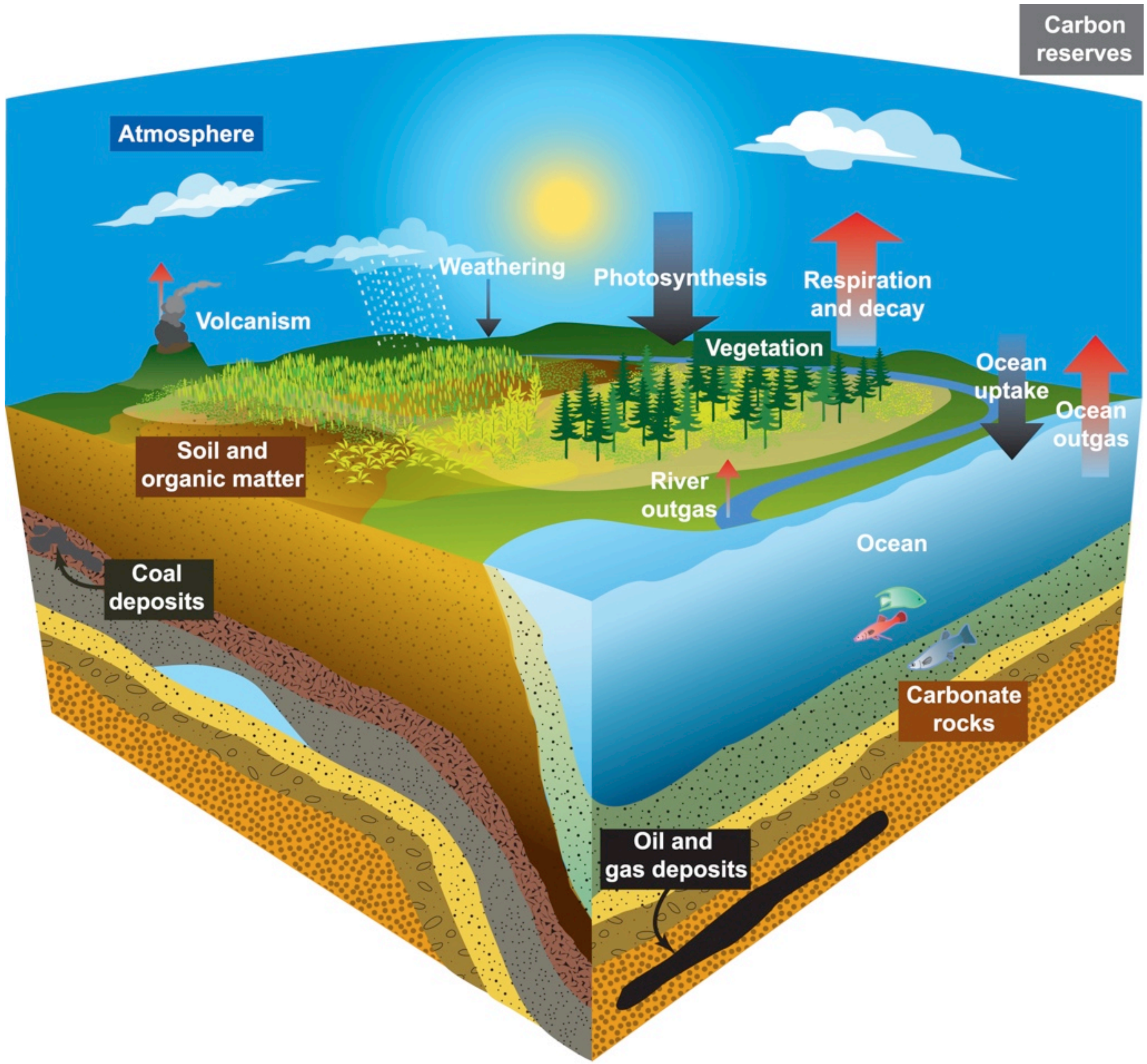
Sources: 2000-2003 Strategies Unlimited, 2006 EPIA "solar generation", 2007 LBBW Report, 2010 SolarBuzz

Does an increase in atmospheric CO_2 influence the Earth's temperature? **Yes.**

Is CO_2 increasing, and is that increase due to human activity? **Yes.**

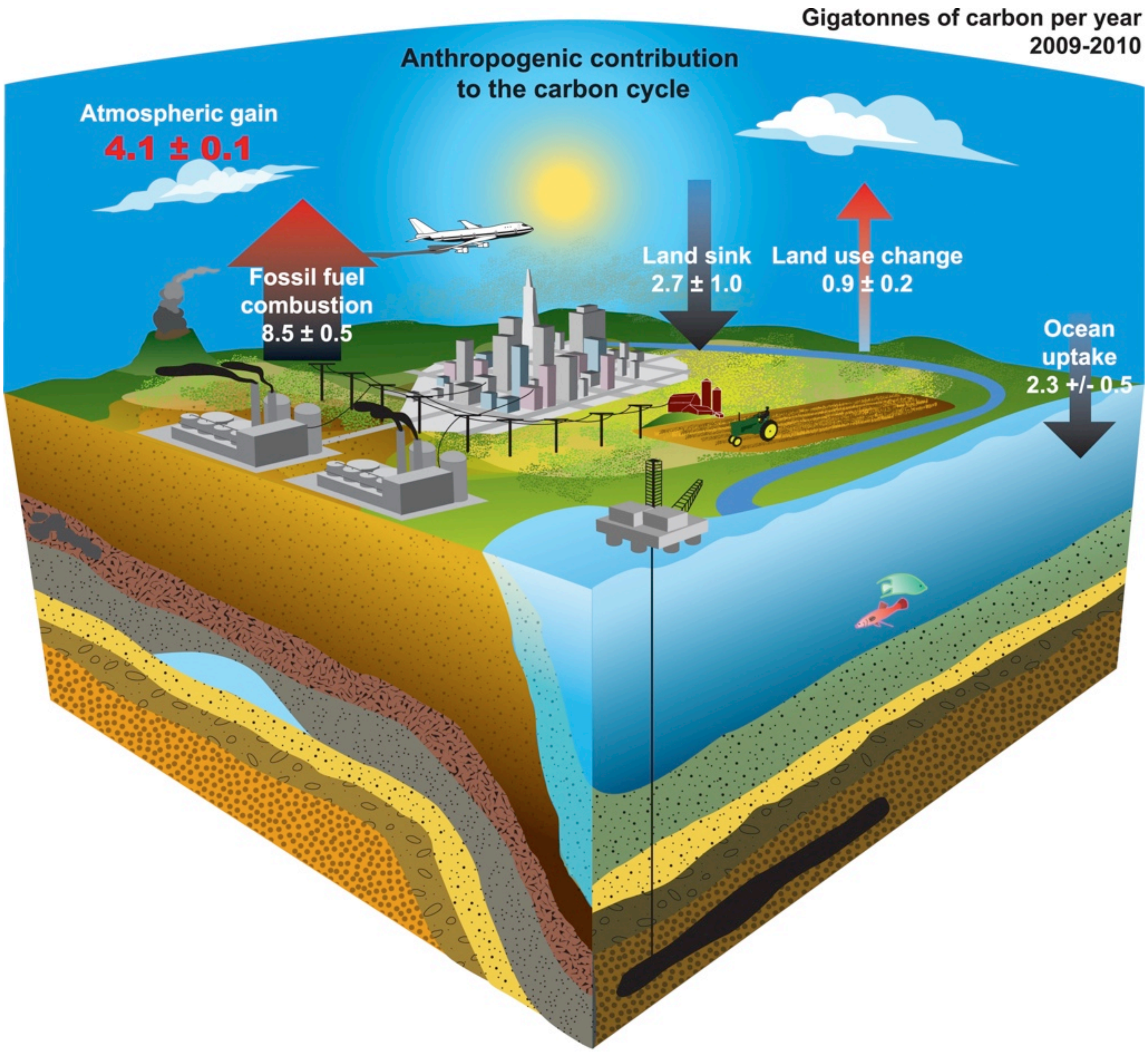
Can't we simply adapt to any changes that might arise from changes in CO_2? **We don't know, but there are substantial risks...**

Carbon Cycle 1.0: relatively stable geochemical cycles



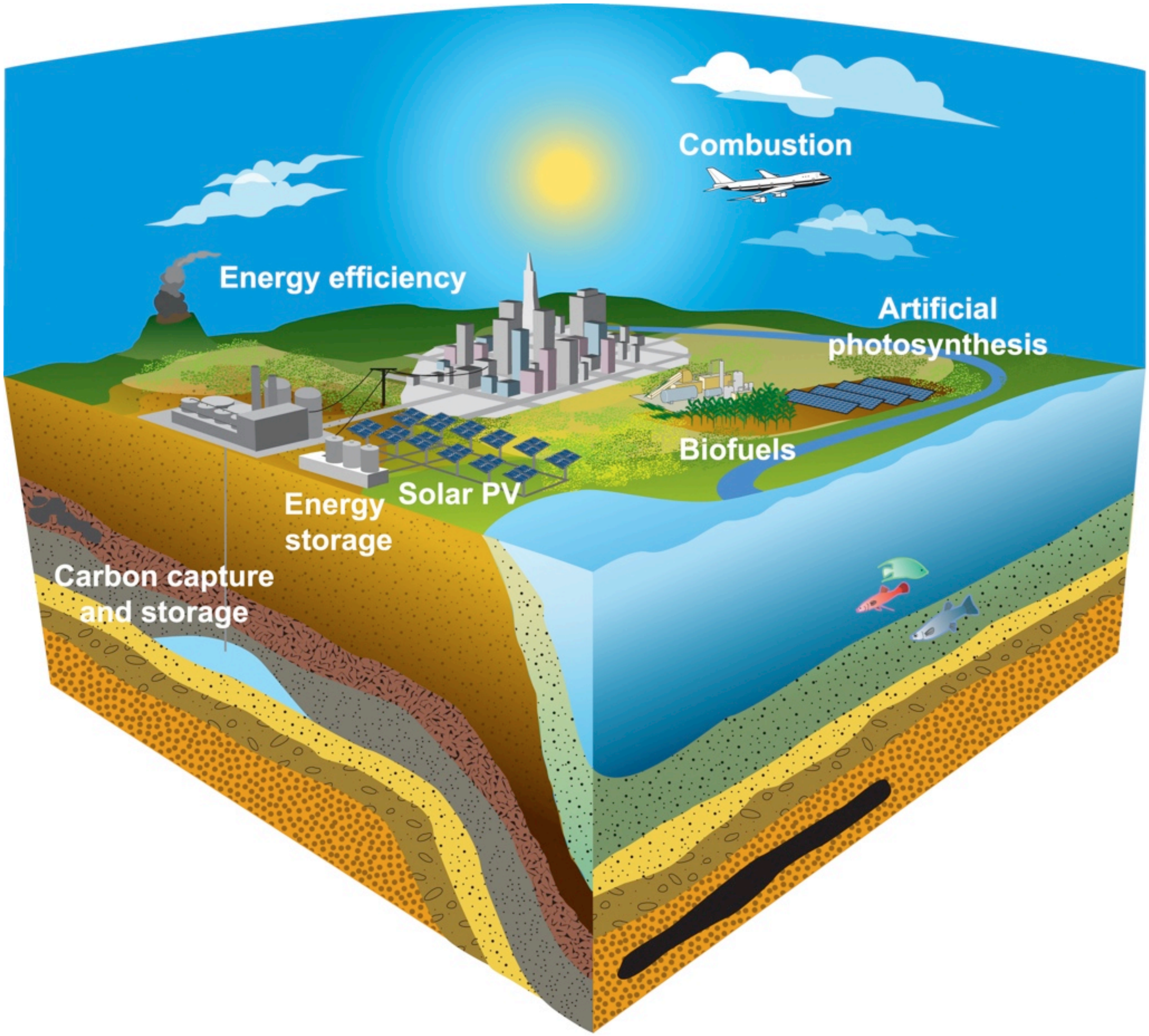
50,000 BC - 1750 CE
average net atmospheric gain: **0.0 ± 0.02** gigatons carbon per year

Carbon Cycle 1.x: An increasingly perturbed system



Net flux of C due to human activity ~100X natural geological flux

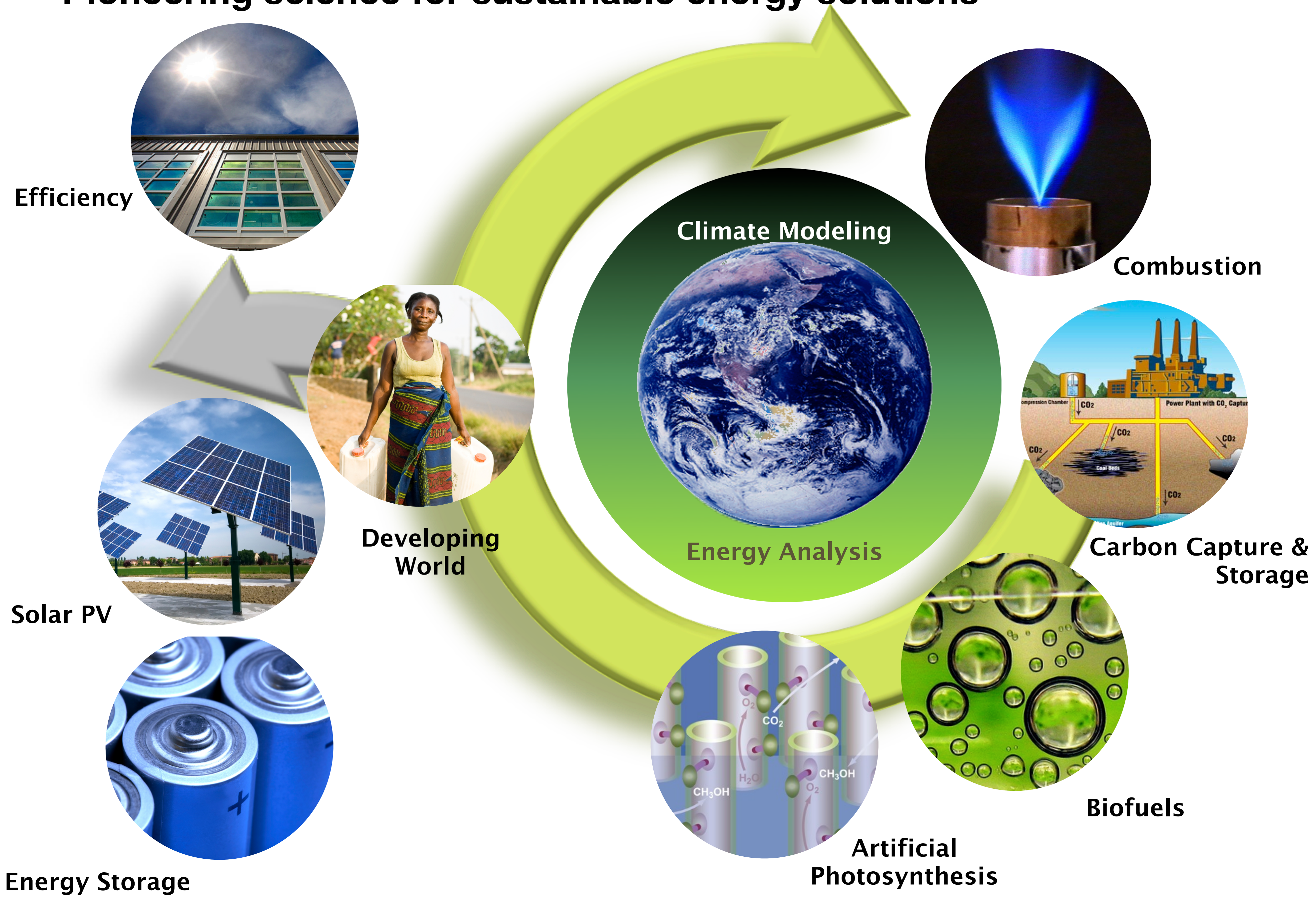
Carbon Cycle 2.0: Restoring balance to the carbon cycle



Balance can be restored while allowing for growth in population and wellbeing

Carbon Cycle 2.0

Pioneering science for sustainable energy solutions



CC2.0 core objectives/components

- Advance fundamental sciences underpinning energy:
  - Materials science, chemistry, biochemistry and biophysics to pave the way for new energy-producing and energy-saving technologies
  - Biology, geology, hydrology, and ecosystem dynamics to understand natural feedbacks in the climate and hydrologic systems and to promote carbon sequestration and alternative low-carbon natural energy sources
  - Climate simulations to enable clear definition of climate change impacts and, by integrating with energy analysis, improve life-cycle analysis of mitigation strategies and new energy technologies
- Promote integration of applied-, use-inspired- and fundamental research to focus research toward scalable technologies that will impact the global carbon balance, and efficiently transfer fundamental knowledge into technology development.
- Be a global innovation hub for science, technology and policy solutions to the world's most critical energy and environmental challenges

BERKELEY LAB
Lawrence Berkeley National Laboratory

Carbon Cycle 2.0

CC2.0 core objectives/components

- Promote the construction of key analytical and computational facilities at Berkeley Lab that will facilitate next generation chemical-, materials-, biological- and geo-science.

- Educate the public, the neighboring community, and laboratory staff about energy-climate issues and the role the Lab is playing in addressing them.

- Develop partnerships with UC Berkeley, other National Labs and Universities, and industry, to enhance Berkeley Lab's potential to contribute to energy-climate solutions.

- Greatly improve energy efficiency and decrease the carbon footprint of the Lab Site through the use of innovative building design and technologies

BERKELEY LAB
Lawrence Berkeley National Laboratory

Carbon Cycle 2.0

New and developing Initiatives for CC2.0

Institute for Energy for the Developing World

Providing low-cost low-energy devices to developing countries to mitigate the adverse effects of large scale inefficient and carbon-intensive energy use while improving the lives and health of large numbers of people

Building Energy Efficiency

An expanded LBNL Sustainability Plan is in the works.   Decrease energy usage and carbon footprint of the lab while maintaining state-of-the-art research capabilities

Advanced Catalysis Research

The merger of heterogeneous and homogeneous catalysis in the size ranges of 1-10 nm. Theory and computation will greatly augment the process of discovery and refinement.

New and developing Initiatives for CC2.0

Biosequestration/Ecogenomics Center

Advance understanding of microbial community processes and feedbacks in dynamic ecosystems; environmental ‘omics through soil processes, phylogenetics, synchrotron imaging, climate change feedbacks...

Institute/Center for CCS

Increase coordination of all our efforts in Capture and Sequestration.

Center for (Integrated Earth System Modeling/Energy Analysis/ Integrated Assessment)

Understanding the environmental, economic and climate impacts of new and prospective energy technologies and climate change mitigation strategies. Development is well underway; integrate energy analysis

BERKELEY LAB
Lawrence Berkeley National Laboratory

Carbon Cycle 2.0

New and developing Initiatives for CC2.0

Batteries/Energy Storage
There is still a reasonable chance that there will be a Hub in this area.

Other possibilities under evaluation

Combustion
build on current close collaboration with SNL/Livermore

Geothermal Research Institute
Possible collaboration with SNL/Albuquerque

Critical Materials for Energy (e.g. Lanthanides)

Carbon Cycle 2.0 Seminar Series

January 6: Sam Deutsch, Swiss National Science Foundation fellow, Joint Genome Institute

January 13: Steve Selkowitz, Building Technologies Head, EETD, The Future of Windows

January 21: Curt Oldenburg, Geologic Carbon Sequestration Program Head, ESD, CO_2 as cushion gas for energy storage

January 26: Eric Masanet, Deputy Leader, International Energy Studies Group, EETD, Integrated Energy Analysis

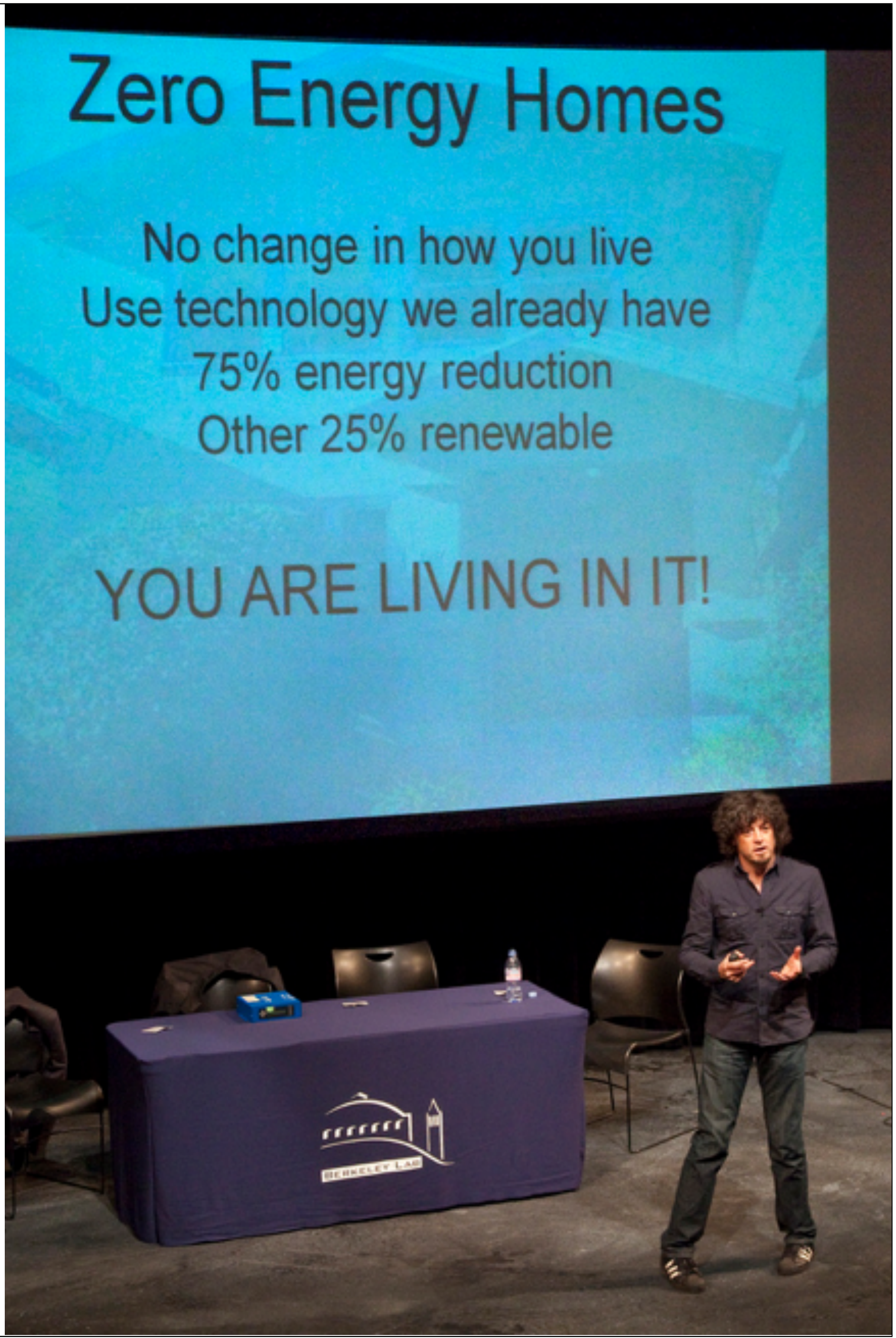
February 4: Ali Javey, Faculty Scientist, MSD, Solar and Nanoscience

February 10: Jim McMahon, Head, Energy Analysis Department, EETD

February 17: Axel Visel, Scientist, Genomics Division

February 24: Eoin Brodie, Staff Scientist, Ecology Division, ESD, Ecogenomics and microbial community uptake of CO_2

carboncycle2.lbl.gov/seminar_series_schedule.html



Other components of CC2.0

***CC2.0 seminar series starting Jan. 2011*.**
Topics to cycle between energy technologies, carbon cycle research, basic research, industrial or policy-oriented invited speakers. Once per month, broadly advertised as a Labwide lecture series.

Internal Hubs:
Possibly stand up internal “Hubs” to bring together scientists with different expertise to work on specific problems. The initiatives listed above are examples, but the extent of co-location is the other issue

Connecting with Industry
We will be establishing an Industrial Advisory Board for CC2.0. Also the idea of having more specialized *ad hoc* committees from industry to give us advice on specific research/technology areas

BERKELEY LAB
Lawrence Berkeley National Laboratory

Carbon Cycle 2.0

Questions to keep in mind that are central motivations for CC2.0:

Is our energy and environment research successful enough?

Where are the key S&T breakthroughs going to occur?

Are we focusing on the right ones; can we do better?

BERKELEY LAB
Lawrence Berkeley National Laboratory

Carbon Cycle 2.0

A positive vision for restoring balance to the carbon cycle while allowing for global growth in population and wellbeing